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THE HOT WATER SUPPLY OF THE HOT SPRINGS, ARKANSAS[1]

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INTRODUCTION

An investigation of the geology of the hot springs in the Hot Springs National Park was recently undertaken for the purpose of determining whether the supply of hot water can be increased. Some new facts were obtained, earlier work critically examined, and recommendations made. The problem is intimately related to the ultimate origin of the water. Thus an investigation begun solely for economic reasons led to a consideration of one of the most

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intricate and uncertain realms of geologic theory. Is the hot water of meteoric, juvenile, or mixed origin? On the answer to this question depends, in a measure, the future of Hot Springs, Arkansas.

ACKNOWLEDGMENTS

To the officials of the National Park Service, through whose co-operation the work was undertaken, the writer is indebted for the opportunity of making this study. The local officers of the Park Service and Colonel John R. Fordyce extended numerous courtesies in Hot Springs. Messrs. H. G. Ferguson, O. E. Meinzer, Clyde P. Ross, and W. D. Collins have read the manuscript and offered valuable suggestions. Mr. H. D. Miser has generously allowed the use of much unpublished material from his extensive researches in the geology of Arkansas.

CHARACTER OF THE HOT WATERS

The waters of forty-six springs have been analyzed by Haywood.[1] The mineral contents vary from 170 to 310 parts per million, and in only a few of the springs do the mineral contents fall below 270 parts or rise above 290 parts. Silica is an important constituent ranging from 32.5 to 52.3 parts per million but being usually between 44 and 47 parts. Calcium (Ca) ranges between 26 and 50 parts per million while the bi-carbonate radicle (HCO_3) ranges between 94 and 172 parts per million. The excess of carbon dioxide is satisfied by small amounts of magnesium, potassium, and sodium. The sulphate radicle ranges from 6 to 28 parts per million, and chloride from 2.36 to 3.33. Their salts therefore form only a small part of the total solids. Small quantities of manganese, traces of phosphorus, of combined nitrogen, iron, and aluminum are present. Boron, iodine, and bromium are reported as small quantities or in traces.

The waters of two cold springs which are located at the pavilion north of the Arlington Hotel have a mineral content of 36.4 and 43.7 parts per million. The water is similar to the hot water except

[1] J. K. Haywood, *Report of an Analysis of the Waters of the Hot Springs*, etc. Sen. Doc. 282, 57th Congress, 1st Sess. (1902), pp. 1–78.

for lower mineralization and greater proportionate content of silica and magnesium.

The contrast in mineral content between the hot water and the two cold springs mentioned above seems to be general in the region, and in a later paragraph the available temperature measurements are discussed. In the table below the water of one of the hot springs is compared with four other springs in Garland County. Big Chalybeate, Mountain Valley, Blanco, and Dripping springs are

ANALYSES OF SPRING WATERS IN GARLAND COUNTY, ARKANSAS

(Parts per million)

Constituents	A	B	C	D	E	F	G	H	I	J	K
Silica (SiO_2)	45.6	3.8	16	22	14	12.5	15.1	6.5	5.1	12	15
Iron (Fe)	.2	7.4	.2	.3	1.2	3.4	3.4	.2	.9	4.6	6.3
Aluminum (Al)			1.2	.3	Tr.			.1			.5
Calcium (Ca)	46.9	70	78	83	76	1.9	3.8	5.3	1.7	3.8	1.4
Magnesium (Mg)	5.1	4.1	12	8.4	2.9	1.4	1.4	.7		2.4	1.5
Sodium (Na)	4.7	1.4	6.5	3.9	2.1	2.1	2.2	1.5	.8	.5	2.4
Potassium (K)	1.6	3.1	.5	3.3	.5	.9	1	.3		.1	.9
Bi-carbonate radicle (HCO_3)	168.1	260	284	288	228	12.1	15.1	18	8	2.4	9
Sulphate radicle (SO_4)	7.8	9.4	25	8.2	12	2.5	2.3	1.9		21	16
Chloride radicle (Cl)	2.5	2	4.4	7	0.2	1.8	2	2.7	2.9	3.3	4.4
Total solids (calculated)	198.5*	229.7	283	278.7	226.8	42	41	28.3	17.6	49.5	52.4

* Total solids determined.

3.600 ppm

EXPLANATION OF TABLE

A. Big Iron Spring, No. 15 of Hot Springs group. Small amounts of nitrogenous material; PO_4, .05; BO_3, 1.29; Br and I, trace; Ba and Sr, trace; Li, trace; gases, nitrogen 8.8, oxygen, 3.79, carbon dioxide (free) 6.92, cubic centimeters per liter at 0° C. and 760 mm. pressure. Analyst, J. K. Haywood, 57th Congress, Sen. Doc. No. 282, p. 46.

B. Big Chalybeate Spring; NW. ¼, SE. ¼, Sec. 22, T. 2 S., R. 19 W. Analyst, A. E. Menke. Reported by J. C. Branner, "Mineral Water of Arkansas," *Arkansas Geol. Survey Ann. Rept. 1891*, Vol. I (1892), p. 28.

C. Mountain Valley Spring, Sec. 19, T. 1 S., R. 19 W., 12 miles north of Hot Springs. Reported by Branner, *ibid.*, p. 69.

D. Blanco Spring, NE. ¼, Sec. 1, T. 2 S., R. 21 W. Reported by Branner, *ibid.*, p. 30.

E. Dripping Springs, one of Grandma Chase's springs, 6 miles northeast of Hot Springs. Reported by Branner, *ibid.*, p. 48.

F. Liver Spring. Cold spring in pavilion north of Arlington Hotel. Small amounts of nitrogenous matter; PO_4, trace; BO_3, trace; Br and I, trace; Li, trace; gases, nitrogen 14.36, oxygen 6.24, carbon dioxide (free) 21.8, cubic centimeters per liter at 0° C. and 760 mm. pressure. Analyst, J. K. Haywood, *op. cit.*, p. 75.

G. Kidney Spring. Cold spring in pavilion north of Arlington Hotel. Small amounts of nitrogenous matter; PO_4, BO_3, Br, I, and Li, traces; gases, nitrogen, 15.3, oxygen 5.3, carbon dioxide (free) 28.5. Analyst, J. K. Haywood, *op. cit.*, p. 76.

H. Happy Hollow Spring, 600 yards north of Arlington Hotel. Reported by Branner, *op. cit.*, p. 52.

I. Same as above. Analyst, R. B. Riggs. Reported by Branner, *op. cit.*, p. 53.

J. Red Chalybeate Spring, one of Grandma Chase's springs. NE. ¼, NE. ¼, Sec. 25, T. 2 S., R. 19 W. Reported by Branner, *op. cit.*, p. 50.

K. Happy Hollow Chalybeate, 100 feet west of Happy Hollow Spring. Reported by Branner, *op. cit.*, p. 54.

all relatively strong springs, though none of them are considered to be "hot" springs. The two cold springs in the pavilion, Liver and Kidney, are small seeps and their waters are similar in type and total content with Happy Hollow, Happy Hollow Chalybeate, and Red Chalybeate springs. The last-mentioned spring was not seen but the two Happy Hollow springs and the springs in the pavilion have their origin in the storage of rain water in soil, talus, and the upper fractured part of the underlying rocks. There seems then to be a notable difference between the shallow meteoric waters and the waters of larger springs.

In 1904 Boltwood[1] determined the radioactivity of samples from forty-four springs. He found no evidence of radium salts in the water and attributes the radioactivity to the presence of radium emanation, a gas. The intensity of radioactivity varies from 0.5 to 265.8, a numerical expression for the equivalent uranium represented by the radium emanation ($g \times 10^{-4}$ U). There are, therefore, great differences in the radioactivity of the springs, but their average intensity is 24.9. The cold springs north of the Arlington have activities of 17.4 and 106.8. The spring having an activity of 106.8 is exceeded by only one of the hot springs, and the other has an activity not far from the average of the hot waters. Boltwood says: "As a general summary it can be stated that it has been found impossible to establish any connection between the temperature, flow, location, or chemical composition of the water of the springs and the observed differences in the radioactive properties."[2]

Previous observations on temperature have been reviewed by Weed:

> In 1804 Dunbar and Hunter recorded a temperature of 100° F., for the larger spring and 154° F. for another spring. . . . . The comparison of the old records with those recently made shows that the highest temperature known today is 147° F. as against 154° in 1804, and 150° by Glasgow and 148° by Owen in 1860. In a number of springs there is a decline of 2° since the latter date. Such a slight difference might, however, be due to differences in the manner or place of taking temperatures, or the instruments used in the

[1] Bertram B. Boltwood, *Ann. Repl. Secy. of Interior*, 1904; also *Amer. Jour. of Sci.*, 4th Ser., Vol. XX (1905), pp. 128–32.

[2] *Ibid.*, p. 132.

earlier years may not have been accurate. In one instance, that of Alum Spring, there is a marked decrease in temperature. . . . . In 1804 this had a temperature of 132°. In 1859 . . . . 133° . . . . and today it is but 114.8°.[1]

Haywood[2] gives temperature measurements for forty-four hot springs which range from 95.4° to 147° F. For thirty-nine springs he gives two measurements each, separated by about two months' time. In fourteen of these thirty-nine springs there is a decrease in temperature, in eighteen there is an increase, and in seven there is no change during this interval of about two months. The average difference between readings is 1.5° F. The maximum decrease is 6.3° F. and the maximum increase 6.4° F. With such unsystematic discrepancies in the measurements of a competent observer with good instruments, no conclusion can be reached as to a general decrease in temperature or to the character of the probable variations in temperature.

The Hot Springs are usually considered to be the only hot springs of the region. Three warm springs, however, are known from the vicinity of Caddo Gap, about 50 miles west of Hot Springs. Data concerning these springs collected in 1915 by H. D. Miser are given in the following table:

SPRINGS NEAR CADDO GAP

Name	Location	Geological Formation	Temperature (Degrees Fahrenheit)
Springs in bed of Caddo River at Caddo Gap.....	NE. ¼, Sec. 19 T. 4 S., R. 24 W.	Upper part Arkansas novaculite	
North opening.....	.....	.....	94
South opening.....	.....	.....	96.8
Spring on Little Missouri River.....	N. ½, Sec. 17 T. 4 S., R. 27 W.	.....	74.3
Spring on Redland Mountain.....	SW. ¼, Sec. 12, T. 5 S., R. 26 W.	Arkansas novaculite	77.0

[1] W. H. Weed, "Notes on Certain Hot Springs of the Southern United States," *U.S. Geol. Survey, Water-Supply Paper 145* (1905), pp. 204–5. See p. 439 of this article for references to Weed's authorities.

[2] *Op. cit.*, pp. 30–31.

Certain springs near Hot Springs conform to and others are above the mean annual temperature of the air at Hot Springs which, based on the thirty-year record of the United States Weather Bureau, is 60.5° F. To this temperature the water of "ordinary" springs should closely approximate. Springs above the normal temperature are probably common as shown by the table below:

TEMPERATURE OF GARLAND COUNTY SPRINGS

	Degrees Fahrenheit
Big Chalybeate*	78.9
Grandma Chase's Springs:*	
Dripping Spring	59.2
Red Chalybeate Spring	62.8
Happy Hollow Chalybeate*	64.6
(Not Happy Hollow Spring)	
Potash Sulphur Springs:*	
West Spring	64 –71.6
South Spring	70.2–72
East Spring	68 –69.8
Springs in Pavilion† north of Arlington Hotel:	
Liver Spring	46.4
Kidney Spring	55.4

* J. C. Branner, *op. cit.*, pp. 28, 48, 50, 54, and 77–81.
† J. K. Haywood, *op. cit.*, pp. 75 and 76.

GEOLOGIC SETTING OF THE HOT SPRINGS

Most of the following discussion of the general geology of the region is condensed from a paper by Miser[1] and from the manuscript of a geologic folio by Purdue and Miser,[2] to be published by the United States Geological Survey. The geologic map, Figure 1, is largely a redrawing of the map in this folio. The Hot Springs are situated in that part of Arkansas known as the Ouachita Mountains. These mountains are composed of numerous nearly east to west ridges and several intermontane basins. Some of these mountains are simple ridges, but others are small ranges. The

[1] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas," *Amer. Jour. of Sci.*, 5th Ser., Vol. II (1921), pp. 62–89.

[2] Purdue and Miser, "Hot Springs and Vicinity Quadrangle Geol. Atlas of U.S.," *U. S. Geol. Survey*, folio, in preparation.

Hot Springs are located in the southern edge of one of these ranges called the Zigzag Mountains, and on the northern border of a lowland called the Mazern intermontane basin.

The rocks of the Ouachita Mountains are nearly all of sedimentary origin, but at Magnet Cove and Potash Sulphur Springs there are small areas of igneous rocks and at numerous localities near by there are small dikes.

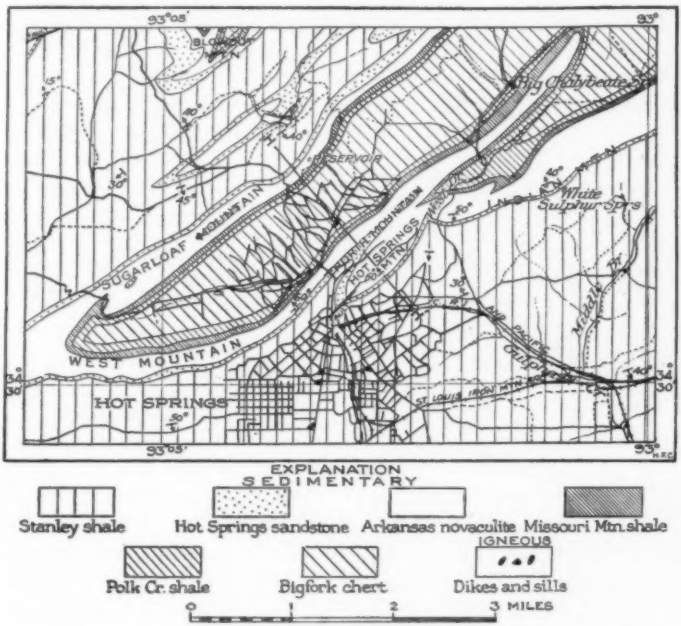

FIG. 1.—Geologic map of vicinity of Hot Springs, Arkansas, after Purdue and Miser.

The sedimentary rocks are indurated and hard, but are only slightly affected by metamorphism. The maximum thickness of the rock beds exposed in the Ouachita Mountains is 37,000 feet, but only a fraction of this total is exposed in the vicinity of the Springs.

The rocks exposed near the Hot Springs consist of the following, though both older and younger are known in the Ouachita Mountains:

GENERAL SECTION OF ROCKS NEAR HOT SPRINGS, ARKANSAS

Geologic Age	Name of Formation and Description	Thickness, Feet
Carboniferous (Mississippian)	Stanley Shale; black, fissile, clay shale, and hard compact sandstone	3,500±
	Hot Springs Sandstone; hard quartzitic laminated gray standstone with heavy bedded conglomerate at the base	200
	Unconformity	
Devonian	Arkansas Novaculite; upper half mainly thin-bedded novaculite and black shale; lower half massive novaculite	500±
	Unconformity(?)	
Silurian	Missouri Mountain Shale; clay shale generally dark greenish drab to black but red in many places	150
	Unconformity(?)	
Ordovician	Polk Creek Shale; black graphitic shale in which graptolites are abundant	200
	Bigfork Chert; thin-bedded gray to black chert much shattered and black shale	700

The rocks mentioned above were deposited one above the other in great sheets. Since their deposition they have been subjected to intense lateral compression which besides lifting the area has produced folds of a general east and west trend. Near the springs these folds have a northeast and southwest trend and the edges of the strata now appear at the surface, and on the map form great looping curves. The major folds consist of numerous smaller folds only a few miles in length, overlapping each other lengthwise. It is with these smaller folds that the springs are associated.

The structures which have the most to do with theories of the origin of the spring waters are the anticlinal fold whose limbs inclose the valley between West, Indian, and Sugarloaf mountains, the synclinal fold of North Mountain, and the anticlinal fold of

Hot Springs Mountain. The character of these folds is brought out in Figures 1 and 2.

GEOLOGY OF THE SPRINGS AREA

The hot water rises in an area of about 20 acres that lies along the east side of Hot Springs Creek, at the southwest base of Hot Springs Mountain. One spring lies west of the creek. Five are said to have risen in the bed, though only one of these can now be found. The spring area is marked by a deposit of calcareous tufa (travertine) from a few inches to eight feet thick over the older rocks. To the tufa the springs are daily making additions, though the present structures for collecting the waters have reduced the rate of formation of the tufa.

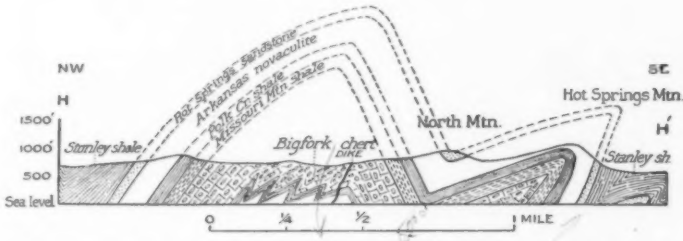

FIG. 2.—Geologic cross-section from Sugarloaf Mountain to Hot Springs Mountain (line *H–H'*, Fig. 1), after Purdue with modifications.

The grounds and springs were carefully mapped by Captain R. R. Stevens, U.S.A., in 1890, and he mapped the tufa, hard-rock outcrops, and springs. Figure 3 reproduces his boundaries for the tufa and for rock outcrops, except that corrections in the rock outcrops have been made at critical points during this investigation. On this map (Fig. 3), the boundaries of the geologic formations have been traced. Landscape gardening, roads, walks, and buildings all tend to conceal outcrops and in a number of places, as stated below, the location of geologic boundaries is uncertain.

The Hot Springs sandstone outcrops on Fountain Street, in Happy Hollow, where it is nearly vertical. From this point it extends along the foot of Hot Springs Mountain southwesterly

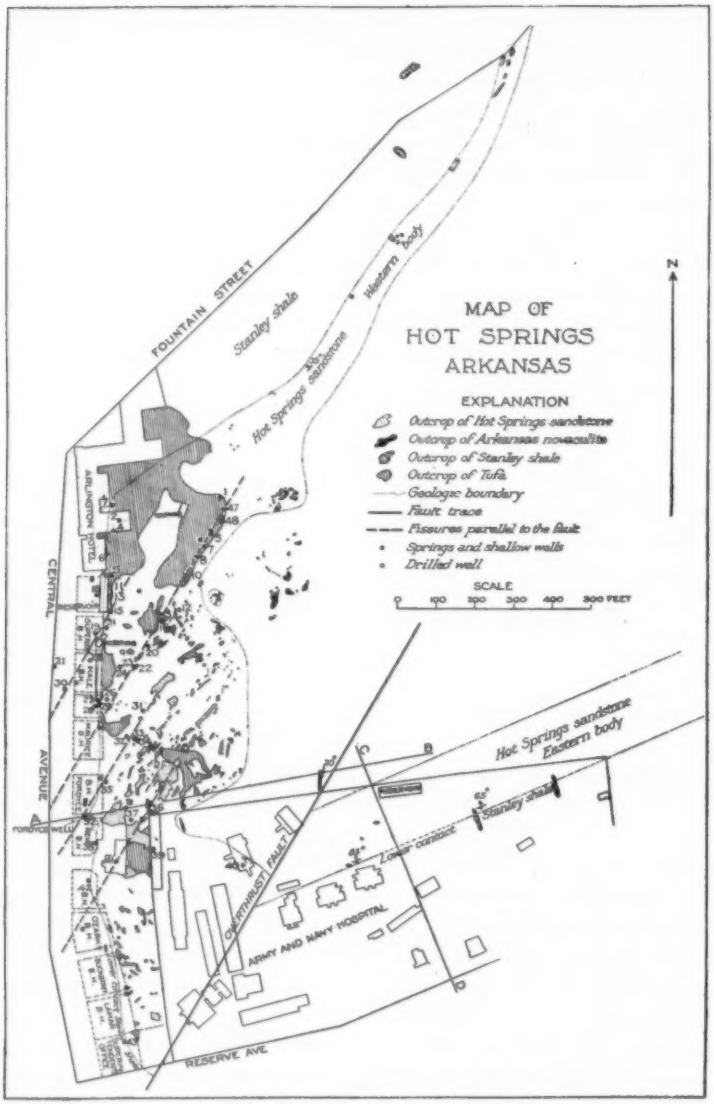

FIG. 3.—Map of the spring area, base and outcrops from Captain R. R. Stevens, U.S.A., 1890.

to the Arlington Hotel and then swings in a broader north and south belt to Reserve Avenue. In this broader belt it has a dip of about 30° and the contact with the overlying Stanley shale is well displayed in the basement of the Maurice, Fordyce, and "new" bathhouses. The lower contact of this body of Hot Springs sandstone extends along the hillside above the springs from the vicinity of the nurses' dormitory in the hospital grounds northwest. In general this contact can be located within 25 feet.

South of Reserve Avenue there are no outcrops of the sandstone, nor are there any in the western part of the hospital grounds.

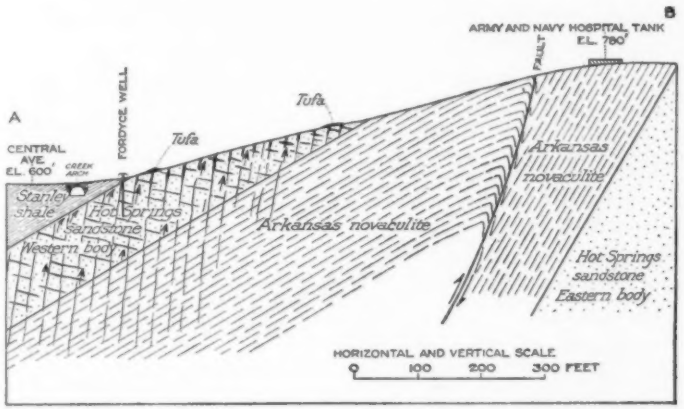

FIG. 4.—Geologic cross-section on line *AB*, Figure 3, through Fordyce well

Since the sandstone is hard and commonly produces outcrops it is assumed that the sandstone does not extend southward any appreciable distance beyond the park line.

This western body of sandstone is the northwestern limb of the Hot Springs Mountain anticline which in its extension along Bathhouse Row forms the nose of the plunging structure. Figure 4 is the cross-section of this part of the mountain on the line *AB* which shows the relation of this body of sandstone to the other rocks.

A second body of Hot Springs sandstone begins on the southeast flank of Hot Springs Mountain and extends southwesterly within the hospital grounds. This eastern body of sandstone dips north-

westerly and is underlain by the younger Stanley shale and overlain by the older Arkansas novaculite. Obviously this body is the overturned southeastern limb of the Hot Springs Mountain anticline. Figure 5 is a cross-section of this part of the mountain and shows the relation of this body of sandstone to the other rocks.

The relation of these two bodies of sandstone once a continuous layer is somewhat uncertain because of the lack of outcrops in the western part of the hospital grounds. If the two bodies are continuous, an extremely close fold is necessary to bend the bed

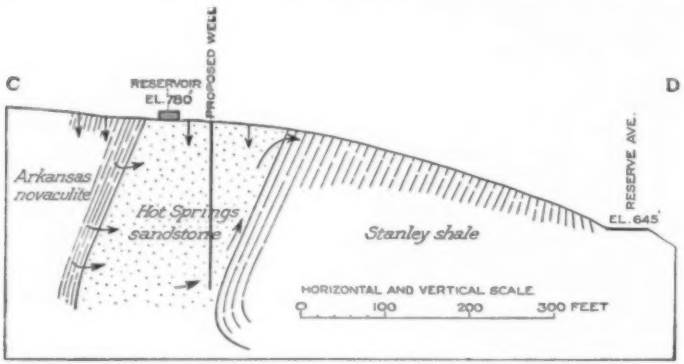

FIG. 5.—Geologic cross-section on line *CD*, Figure 3, through proposed cold-water well.

from a position dipping 30° west at the superintendent's office to 65° northwest near the reservoirs on the hospital grounds, 900 feet away. It seems likely that instead of bending, the beds broke along a thrust fault and this interpretation is shown in Figures 1 and 3. This postulated fault would have a plane which dips to the northwest and a trend about 30° east of north.

RELATION OF THE SPRINGS TO THE WESTERN BODY OF SANDSTONE

As shown in Figure 3, all the hot springs shown on maps since 1890 or now in existence emerge from the outcrop of the western body of sandstone or from the immediately adjacent Stanley shale. Similarly all the bodies of tufa which indicate the position

of springs active or formerly active lie on the sandstone or on the immediately adjacent Stanley shale.

The Hot Springs sandstone of this body is somewhat harder than normal, is a darker color, and is much fractured. These fractures are commonly sealed with quartz and calcite, both apparently deposited by the hot waters. In a number of instances, notably in the Maurice and "new" bathhouses, where excavation has exposed the sandstone, the hot water can be seen emerging from the cracks and fissures of the rock.

The fractured sandstone is then the conduit for the hot water which is prevented from breaking out in the lower depression (the creek bed) by the Stanley shale through which it maintains only a few openings. Similarly the water closes the cracks and joints of the sandstone by deposition and consequently all the springs do not break out at the contact of the sandstone and Stanley shale but many of them emerge higher up the hill.

On the hillside, back of the bathhouses, the outcrops of sandstone are each extended in a northeasterly direction. Each outcrop in addition is marked by strong, nearly vertical jointing in this direction. The maps show also that the spring openings are arranged in lines of which the most marked is that belt of springs from the Egg Spring, No. 1, to the Maurice Bathhouse, which includes the strongest springs of the group. Four such lines of springs are marked on the map. These lines are approximately parallel to the thrust fault, postulated between the east and west bodies of the Hot Springs sandstone. A fifth line may be drawn parallel to the contact of the sandstone with the shale, but this line includes many springs situated on other lines. Obviously, if the sandstone were uniformly permeable and the shale uniformly impermeable, all the springs would lie on the contact.

The strong jointing in the sandstone, and the distribution and elongation of outcrops indicate a fracturing of the sandstone in a direction north northeast parallel to the Hot Springs anticline. Weed[1] noted the line of springs extending from Egg Spring, No. 1, to the Maurice Bathhouse and suggested that this line was a "fault fissure." It seems more likely that this line and the three

[1] *Op. cit.*, p. 201.

other lines of springs simply mark the position of more open joints like the joints visible in the outcrops but that all the joints are parallel to and related in origin to a thrust fault which lies to the south of them. Doubtless similar cracks might have been formed by simple folding. However, the very absence of outcrops in the western part of the hospital grounds seems to be an argument in favor of faulting which would shatter and comminute the rocks along the line of the fault and thus make them more susceptible to erosion. Folding without faulting, on the other hand, would give a a double thickness of sandstone which would be almost sure to outcrop, and this same folding would presumably so shatter the sandstone as to make the line of the fold the locus of springs.

Whatever the ultimate origin of the water, it emerges through the cracks and joints of the Hot Springs sandstone and mainly along the strong jointing parallel to and probably related in origin to the postulated thrust fault. The bearing of these relations on development of the springs is obvious.

THEORIES OF ORIGIN OF THE HOT WATER

In 1804 William Dunbar[1] and Doctor Hunter visited the springs. They observed that the mountain was "principally siliceous, some part of it being of the hardest flint, others a free-stone extremely compact and solid and of various colors. The base of the hill, and for a considerable extent, is composed of a blackish blue shistus, which divides into perpendicular lamina, like blue slate." They make extensive comments on the tufa deposited by the water. They estimated the flow of all the springs at 165 gallons per minute or 237,600 gallons daily. They suggested chemical reactions as the cause of the heat of the water, having found no evidence of volcanic action in the vicinity.

In 1806 a writer relates that he saw a volcanic outburst and streams of molten rock near Hot Springs. He is generally disbelieved by later writers.[2]

[1] Thomas Jefferson, *Message of the President of the U.S. Communicating Discoveries Made in Exploring the Missouri, Red River, and Washita by Captains Lewis and Clark, Doctor Sibley, and Mr. Dunbar*, etc. A. & G. Way, printers, Washington, 1806.

[2] *New York Medical Repository*, Vol. III, No. 1 (1806), pp. 47–50.

In 1860, David Dale Owen,[1] state geologist of Arkansas, published an account of the springs with analyses and observations on temperatures. He rejects all chemical theories of origin of the heat.

> On the contrary, I attribute the cause of it to the *internal heat of the earth*, I do not mean to say that the waters come in actual contact with fire, but rather that the waters are completely permeated with highly heated vapors and gases which emanate from sources deeper seated than the water itself.

Owen believed that the novaculite was a sand rock which had been changed by the "permeation" of heated alkaline waters and considered the hot springs merely the dying phase of this extensive movement of water. He gives, however, no mechanism or conduit for these waters.

In 1892 J. C. Branner,[2] state geologist, discusses the origin of the heat and attributes the heat of the water to "coming in contact with the masses of hot rocks, the cool edges of which may or may not be exposed at the surface."

In 1902 Walter Harvey Weed published a geological sketch of the hot springs.[3] Weed noted that the principal springs are arranged along a line running NNE., parallel to the axis of the fold forming Hot Springs Mountain. He thought this a fault fissure. Fissuring in connection with faulting seems confirmed (p. 438). Weed considered that the purity of the waters, particularly their low content of silica, and the included gas which appears to be dissolved air, all point to a meteoric origin of the water, i.e., that the water is derived from rain and differs from ordinary spring water only in being heated. He believed this heat to be derived from still uncooled igneous rock intruded into the sediments below the springs. The upper parts of similar bodies

[1] David Dale Owen, *Second Report of a Geological Reconnaissance of the Middle and Southern Counties of Arkansas*, etc., pp. 18–27, Philadelphia, 1860.

[2] J. C. Branner, "Mineral Waters of Arkansas," *Arkansas Geol. Survey, Ann. Rept., 1891*, Vol. I (1892), pp. 8–23.

[3] J. K. Haywood, *Report of Analysis of the Waters of the Hot Springs*, etc.; and Walter Harvey Weed, *Geological Sketch of Hot Springs, Arkansas*. Senate Doc. 282, 57th Congress, 1st Sess. 1902. Also with modifications *U.S. Geol. Survey, Water-Supply Paper 145* (1905), pp. 189–206, and separate by Interior Department, 1912.

are exposed at Magnet Cove, Potash Sulphur Springs, and as dikes in the vicinity of the Hot Springs.

In 1910, Purdue[1] published an elaborate paper on the origin of the hot water. He follows Weed in believing that the water has a meteoric origin and that in its passage through the ground derives heat from uncooled masses of igneous rock. He goes a step farther and outlines the structural conditions for the collection and transmission of the water. He believes that the water falls as rain in the anticlinal valley between North and Sugarloaf Mountains, where it is absorbed by the Bigfork Chert. "The considerable thickness of this chert, its much fractured nature, and the thin layers of which it is composed all combine to make it a water bearing formation of unusual importance."

The water having been collected in this formation is confined by the impermeable overlying Polk Creek and Missouri Mountain shales. Thus confined the water is conducted beneath the syncline of North Mountain, where it most probably comes in contact with some uncooled mass of igneous rock. Purdue suggests, but rejects the hypothesis that the water is expelled by the cooling of such an igneous mass.

Lindgren,[2] in 1919, accepts Purdue's views and considers that the springs have "clearly derived their saline constituents from the surrounding sedimentary rocks."

Another hypothesis should be advanced. On this hypothesis the water is of deep-seated origin derived from a covered mass of igneous rock intruded into the sediments, but not showing at the surface, which discharges water expelled from its molten interior by the gradual crystallization of its mass, or the water is derived from a deeper less definite but similar mass and rises to the upper crust through a deep, probably fault, fissure. Such water is commonly called juvenile, i.e., new water coming to the surface for the first time.

[1] A. H. Purdue, The Collecting Area of the Waters of the Hot Springs, Hot Springs, Arkansas," *Jour. of Geol.*, Vol. XVIII, No. 3 (1910), pp. 278–85, 3 figs. Also *Indiana Acad. Sci. Proc. 1909*, pp. 269–75, 3 figs. 1910.

[2] Waldemar Lindgren, *Mineral Deposits*, p. 90. New York, 1919.

JUVENILE VS. METEORIC WATER

One of the great triumphs of modern geology has been to establish that the majority of metalliferous ore bodies, including most quartz veins, are deposited by ascending aqueous solutions which are derived from and excluded from crystallizing igneous bodies.

Granite rocks have been traced into pegmatite veins; pegmatite veins into metalliferous quartz veins; metalliferous quartz veins into quartz veins without impurities. It has thus been shown that aqueous vapors and gases gradually cooling and purging themselves of many substances rise through the crust and approach the surface in a purer and purer state. There is no theoretical objection to cold water with a minimum of mineral matter being attributed to a juvenile origin from an underlying crystallizing igneous mass, except the difficulty of proof. The majority of geologists do not hestitate to ascribe ore deposits to deposition from juvenile water, yet they hesitate to ascribe a juvenile origin to water emerging at the surface. It is well then to examine the criteria on which a discrimination between these two classes of water can be based.

Springs of small volume, and large variation in flow and temperature, can usually be referred to a meteoric origin. There are, however, many difficulties in determining the precise geological structure which gives rise to a particular spring. The requisite structures necessary for such a spring are: (1) an intake area, (2) a reservoir, and (3) a conduit to the surface. Under different geologic conditions the three requisites assume a multitude of forms and vary in size according to the hydraulic conditions. In a previous publication[1] twenty-four named varieties, divided into five groups, are described and illustrated. The field geologist, knowing the many possible structures, may have difficulty in deciding on the right one for any particular spring because of lack of evidence. Deep weathering of the rocks and a mat of vegetation and vegetable mold are usual at springs and tend to destroy, locally at least, the

[1] Kirk Bryan, "Classification of Springs," *Jour. of Geol.*, Vol. XXVII (1919), pp. 521–61, 26 figs.

evidence of structure. However, a group of springs of common origin can usually be identified with the geologic structure to which they are due.

Springs of relatively large volume with little variation in flow or temperature present, especially if they are hot springs, difficult problems. Certain hot springs are undoubtedly of meteoric origin and depend for temperature on the descent of meteoric water from the surface into the crust and its rise, without great loss in temperature, to the surface. Such springs are due to the fracture, usually by faulting of the cover of a definite artesian structure, but unfortunately no adequate description of such a spring has yet been published. Buckhorn, Indian, and Willow springs in Antelope Valley, California, which served as examples of the fracture artesian[1] type of spring, are not thermal. Nearby flowing wells, having water of similar chemical composition, are from 200 to 400 feet deep. The artesian circulation in this valley does not go to great enough depths to yield hot water.

Many springs of steady flow and high temperatures arise in localities where it is impossible to postulate a structure which will receive the water at the surface, carry it to depths, and return it to the surface. Waring[2] found that of ninety-eight groups of hot springs in California, thirty-eight rise from granite or granitic rocks; of 155 carbonate springs, some of which are above the normal temperature, thirty-two occur in granite or granitic rocks. In such rocks the hot waters must arise from below through deep fissures. In California there is a notable association of the springs with faults, to which the fissures may be attributed. From these deep fractures in the crust, juvenile water from underlying magmas or incipient magmas may arise or there may be admixtures of meteoric and even connate waters which have or may have a circulation due to obscure or unknown forces. Certainly it seems simpler to assume that the water is juvenile. Certain springs, such as those near the Fish Springs Range, Utah,[3] are associated with faults of large

[1] Kirk Bryan, *op. cit.*, pp. 553–55.

[2] Gerald A. Waring, "Springs of California," *U.S. Geol. Survey, Water-Supply Paper 338* (1915), p. 154.

[3] Kirk Bryan, *op. cit.*, pp. 533–35.

throw and recent age. This association seems a definite indication of juvenile origin. Hot springs in volcanic regions are probably in part of mixed origin. The presence of uncooled or even molten rock near the surface makes easy the heating of meteoric water and its return to the surface. Doubtless some springs in volcanic regions have a wholly meteoric origin, as Hague[1] has proposed for the geysers of the Yellowstone. Yet beneath volcanoes magmas are crystallizing and expelling water. It is inconceivable that all of this water is absorbed in chemical reactions or in the interstices of the rocks below the surface. Some of it, with its contained minerals and gases, must reach the surface.

Springs with steady flow and without great variations in temperature or quantity, especially if they are hot, must then arise from some deep artesian circulation or be of juvenile origin. The artesian circulation should be susceptible of proof on structural grounds. In the absence of such proof the indication of juvenile origin is very strong.

Elaborate investigations of the chemical characteristics of water, with the object of discovering its origin, have so far proved disappointing. Sodium chloride and sodium carbonate waters from granitic rocks carry a strong presumption of juvenile origin since the ordinary springs of such regions have water of the calcium carbonate type.[2] But unusual substances such as boron and fluorine have been found in spring waters of such diverse types as to be without critical value.

ANALYSIS OF THE MERITS OF THE HYPOTHESES

The question of the ultimate origin of the water in the Hot Springs of Arkansas is not only of intense theoretical interest, but has practical bearings. If the water is juvenile there is presumably a constant supply, diminishing very gradually through the centuries in quantity and temperature. When all the water is conserved by adequate structures it is probable that no more can be obtained. If, on the other hand, the water has a meteoric origin, it is variable

[1] Arnold Hague, "Origin of the Thermal Waters in the Yellowstone National Park," *Bull. Geol. Soc.*, Vol. XXII (1911), pp. 101–22.

[2] W. Lindgren, *op. cit.*, p. 64.

in quantity, fluctuating with the seasons or with the groups of years having heavy or light rainfall. Also if the intake area is adequate, heavy drafts on the springs as by pumping should reduce the quantity in the reservoir and increase the absorption of rainfall in the intake area. Such increase in the volume of water flowing through the system may decrease the temperature of the water, an important consideration from the standpoint of use. A meteoric origin implies an intake area and this area must be found and protected from pollution.

It should be confessed that the present state of the science of geology is so imperfect that a definite conclusion as to the ultimate origin of the water in the Hot Springs cannot now be reached. As pointed out by Weed, the absence of unusual substances in the waters, low mineralization, and a gaseous content of oxygen and nitrogen in the proper ratio to form air are facts which do not show any unusual or non-meteoric origin for the water. On the other hand juvenile waters by deposition might purge themselves of all unusual substances, though if they originally contained sodium chloride there are difficulties in accounting for the loss of this stable compound. The radioactivity of the water, or rather the fact that it contains radium emanation (a gas) as determined by Boltwood in 1904,[1] is not of critical significance, for the amount of radioactivity is not unusual in wells and springs.

The previous temperature determinations are analyzed by Weed who rightly considers that they do not indicate either decrease in the heat or fluctuation in heat. Similar conclusions are reached from previous measurements of the water. But the existing measurements of these factors are neither adequate nor systematic. Fluctuations in temperature and volume are easily determinable if they exist. The critical value of such measurements is so great that it is to be hoped that they will be made for a sufficient period to provide adequate data.

The meteoric hypothesis calls for a structure to carry the water from the intake area at the surface to depths and then return it to

[1] Bertram B. Boltwood, "Annual Report of Secretary of Interior, 1904," *Amer. Jour. of Sci.*, 4th Ser., Vol. XX (1905), p. 168.

the surface. As postulated by Purdue,[1] the water falls on the Bigfork Chert in the anticlinal valley between West and Sugarloaf mountains, is absorbed in the chert and passes below the syncline of North Mountain and arises in the anticline of Hot Springs Mountain. The course of the water is shown in Figure 2. The contact of the Bigfork Chert with overlying beds along the southwestern base of Sugarloaf Mountain (see the geologic map, Fig. 1), is about 850 feet above sea-level. Other parts of the chert outcrop as low as 650 feet, this being the elevation at the point nearest the hot springs. The hot springs break out at elevations between 600 and 694 feet. Parts of the intake area are thus at the same level as the springs and below some of them. Assuming the greatest difference 200 feet, it is doubtful if 200 feet of head or 80 pounds of pressure per square inch is sufficient to force the water through the channel assumed by this hypothesis. Even if this head is sufficient, it is remarkable that the water comes across the strike under the North Mountain syncline, when it could swing northeastward and around North Mountain into the Hot Springs anticline without notable change in level. This path is possible because the North Mountain syncline plunges southwestward and near the "Gorge" of West Branch brings the Bigfork chert near the surface. From this analysis it appears that the postulated structure is a very special hypothesis of dubious validity.

Similarly the hypothesis calls for an uncooled mass of igneous rock below the North Mountain syncline to supply heat, for the internal heat of the earth would not raise the temperature the required amount unless the water descended to 5,000 feet and then came to the surface without loss of temperature. Obviously the postulation of such an igneous body is a special hypothesis, particularly when apparently the water could easily avoid the plug by a change in route as shown before. The occurrence of igneous masses in the neighborhood as at Magnet Cove and Potash Sulphur Springs adds probability to this hypothesis, but these intrusions are thought to be of Cretaceous age, a time so remote that it is stretching credulity to believe that rocks of this age are still uncooled at moderate depths.

[1] A. H. Purdue, *op. cit.*

The emergence of the water through the Polk Creek and Missouri Mountain shales into the Hot Springs sandstone requires no special hypothesis, if the thrust fault with associated jointing and fissuring which seem to be indicated by field relations is granted.

By reference to the table of temperatures, page 430, it will be seen that Big Chalybeate Spring has a temperature above normal. In chemical composition the water is of the calcium carbonate type, and of about the same mineralization as the Hot Springs waters, differing mainly in having less silica, (see table, page 427.) It has a strong and according to local observers a steady flow, which measured by H. D. Mitchell[1] was found to be 186 gallons per minute. This spring lies 5½ miles northeast of Hot Springs on the northwestern flank of the mountain which is the extension of the North Mountain syncline. The spring apparently arises from the Polk Creek shale in the flat valley of a tributary of the West Branch of Gulpha Creek. If the water is derived from rainfall on the Bigfork, which saturating the chert arises through a fracture in the shale, it is difficult to account for the abnormal temperature, 18° above the mean annual air temperature, unless an uncooled igneous plug is postulated for this spring also. The contact of the shale with the chert on the west is less than one-tenth of a mile away and less than 20 feet above the spring. The difference in head seems insufficient to force the water to travel to depths and return. On the other hand, southwest of the spring three-fourths of a mile is another anticlinal area of Bigfork chert which has its contact with the shale at elevations between 620 and 820 feet. It might be postulated that water from this area would flow northwest under the syncline and emerge at Big Chalybeate Spring. This hypothesis has the advantage that a depth of 1,000 to 2,000 feet would be attained, and this depth would doubtless be sufficient to account for the temperature of the water. The spring, however, has an elevation between 620 and 640 feet. For this postulate, also, there appears to be a lack of hydraulic head. The origin of Big Chalybeate Spring is then as much an unsolved problem as the origin of the Hot Springs, but because the waters are both thermal

[1] J. C. Branner, *op. cit.*, p. 29.

and similar in chemical composition, it seems likely that they have a common origin. Special hypotheses are invalidated by this probability.

The meteoric hypothesis then suffers from two main defects: (1) A possible lack of head to force the water through the postulated structure; (2) the very special association of uncooled rock with the structure.

The hypothesis of juvenile origin for the waters when examined is perhaps more satisfactory, but suffers from conspicuous defects.

This hypothesis may take two forms: (1) That there is a buried mass of uncooled igneous rock which is discharging water due to cooling and crystallization; (2) that a fracture or fissure extends from the springs into the deep interior of the earth, similar in character to the great fault fractures and through this fracture deep-seated waters, juvenile or of mixed origin, rise to the surface.

A mass of uncooled igneous rock discharging juvenile water is a hypothesis of the same special character as the uncooled body postulated under the meteoric hypothesis. It is no more unreasonable to assume that it is still crystallizing and discharging water, than that it is not crystallizing, but is still hot enough to heat the water by contact. Moreover, the nearby igneous bodies are of Cretaceous age and there is no other evidence of igneous activity in the general region.

That a deep fracture or fissure exists is also a special hypothesis but only special in that it provides that the water rising in this fissure is warm at the surface. A source of heated water is everywhere present in the deeper crust and in regions of disturbance there is a rise in the geotherms and in some instances at least invasion of batholithic bodies. Deep fissures in this general region, though their position is now almost wholly concealed by erosion, must have occurred as late as the Pleistocene epoch during which time the principal uplift is thought to have occurred. Under a hypothesis of recent faulting the position of the springs at the nose of Hot Springs Mountain anticline is purely accidental except that the rising waters have taken advantage of the preexisting fracture by overthrust of the Hot Springs sandstone and the two underlying shales.

Faulting, except in connection with folding, throughout the general region around Hot Springs, is difficult to establish. However, in the coastal plain region of central and southern Arkansas and adjacent states, Late Tertiary and post-Tertiary faulting have probably taken place. According to Stephenson,[1] small faults are recognized in connection with the Preston anticline. In the Monroe Gas Field[2] a post-Eocene fault with a total displacement of 150 feet has been mapped. The theory of origin of salt domes advanced by Harris[3] rests on the postulate that faulting on an extensive scale has taken place throughout eastern Texas, Louisiana, and southern Arkansas. Quarternary faulting with a displacement of at least 1,000 feet has been shown for the Jennings oil field.[4] A post-Tertiary fault with a throw of 2 feet to the south was noted by Professor H. A. Wheeler[5] and Colonel John R. Fordyce 3 miles north of Stephens, Arkansas, a town 75 miles south of Hot Springs. This fault appears to be very recent.

The recorded evidence of recent faulting is thus incomplete, but the known uplift of Pleistocene time must have offered favorable conditions for faulting however difficult the matter of proof may be. While no recent faulting has been discovered at or near Hot Springs, the foregoing facts indicate that such faulting is not improbable and may yet be found.

The hypothesis of juvenile origin thus also rests on an insecure foundation since it postulates either a special igneous mass or a special fault fissure. For neither of these is there other evidence.

USE AND DEVELOPMENT OF THE HOT SPRINGS WATER

The quantity of the Hot Springs water used for bathing and drinking fluctuates from year to year but has gradually increased. The

[1] L. W. Stephenson, "Contribution to the Geology of Northeastern Texas and Southern Oklahoma," *U.S. Geol. Survey, Contrib. to General Geol., Prof. Paper 120* (1919), pp. 129 ff.

[2] H. W. Bell and R. A. Cattell, *Louisiana Dept. Conservation, Bull. No. 7*, 1921.

[3] G. D. Harris, *Bull. Louisiana Geol. Survey No. 7* (1908), pp. 75 ff., also *Econ. Geology*, Vol. IV (1909), pp. 12–34, and *U.S. Geol. Survey Bull. 429* (1910), pp. 6–10, Pl. 1.

[4] G. D. Harris, "Oil and Gas in Louisiana," *U.S. Geol. Survey Bull. 429* (1910), pp. 56–61.

[5] Letter, October 22, 1921.

private investment in bathhouses and hotels is large and the government investment in the Free Bathhouse and in the Army and Navy Hospital is considerable. The volume of business can be measured by the number of baths given which reached a maximum of 1,194,872 in 1911. A careful engineering study will doubtless lead to improvements in the present system of distributing the water. Even though economies may increase the capacity of the resort to handle patients and visitors, large future growth of Hot Springs as a health and pleasure resort depends on an increased supply of hot water. The practical means by which additional hot water may be obtained are not here discussed, but it is obvious that development can be attempted intelligently only with accurate knowledge of the origin of the water.

The Fordyce Well, shown on Figures 3 and 4, is 6 inches in diameter and $67\frac{1}{2}$ feet deep. It penetrates the Stanley shale and extends into the Hot Springs sandstone. The well has a flow of hot water amounting to 50,000 gallons daily. Since the well appears not to have decreased the flow of any existing spring or well, it must be supplied with water which had previously reached the surface in minor seeps and concealed springs. Other wells in the same geologic position near the contact between the shale and sandstone will save seepage, but will probably dry up the hillside springs. The resulting concentration of flow will be convenient for a single unified distributing system and the substitution of artificial openings for the natural openings or hot springs will be an inconsiderable sentimental loss.

Whether water not to be considered as salvage can be developed by such shallow wells depends on the ultimate origin and the mechanism of flow of the hot water. Each stage in attempted development of new water will raise anew these fundamental questions.

A DEVONIAN OUTLIER NEAR THE CREST OF THE OZARK UPLIFT

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INTRODUCTION

The Paleozoic history of the Ozark Uplift constitutes an extremely interesting stratigraphic study, and one upon which comparatively little has been written. The earlier stages of this history, up to the close of the Canadian epoch, are fairly well known, for rocks belonging to this and the preceding epochs are well exposed throughout the uplift. Of the later history but little is known, for so thoroughly have the subsequent periods of erosion performed their work, that only small and widely separated outliers of the younger formations remain on the higher parts of the uplift. Around the borders of this dome are belts of younger formations, more or less completely encircling it, and it has always been a question as to how far these formations once extended toward the crest of the structure and which of them, if any, completely covered it. Upon this question no two sets of paleogeographic maps agree. One of the chief reasons for this disagreement is lack of information concerning the region, for, as a whole, there has been little detailed stratigraphic work done in the region of the Ozark Uplift.

In the area around Rolla (110 miles southwest of St. Louis and well toward the crest of the uplift) the existence of outliers of Pennsylvanian and Mississippian age has long been known. The former consist of stratified deposits of sandstone and shale, and cover far greater areas than are shown on existing maps.[1] The Mississippian outliers are, for the most part, small areas covered with fossiliferous, residual bowlders,[2] which have apparently weath-

[1] The new geological map of Missouri, now in press, shows many of the larger Pennsylvanian outliers.

[2] Josiah Bridge, "A Study of the Faunas of the Residual Mississippian of Phelps County (Central Ozark Region), Missouri," *Jour. Geol.*, Vol. XXV (1917), pp. 558–75.

ered out of the basal conglomerates of the Pennsylvanian. In one or two instances, however, there are good reasons for believing that there are small areas of Mississippian rocks which are still in place, and which rest unconformably upon the Jefferson City dolomite (Beekmantown), as do also most of the Pennsylvanian outliers.

A few months ago the junior author discovered a small outlier containing a fauna which is characteristically Middle Devonian in age. This fauna when identified proved to be of sufficient diagnostic value to place the age of the outlier within very narrow

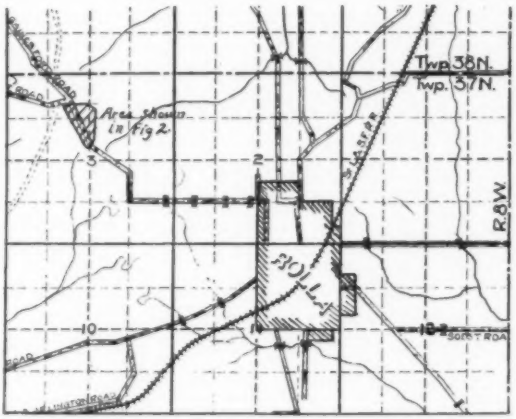

FIG. 1.—Sketch map showing general location of Devonian outlier. The shaded portion represents the area shown in detail in Figure 2.

limits. Inasmuch as Devonian has never before been reported from this area, the finding of this outlier gives a little more light on the history of the uplift, and the purpose of this paper is to describe this occurrence and its fauna, and to add its bit of evidence to the history of the region.

LOCATION AND GENERAL DESCRIPTION

The Devonian outlier lies about 1½ miles northwest of Rolla, in the NE. ¼ NW. ¼ sec. 3, T. 37 N., R. 8 W. (Fig. 1). It is on the east side of the road and lies fifty feet below the crest of the ridge

(Fig. 2). It occupies a little knoll between two gullies, and when first found consisted of a number of knobs of quartzite projecting from the hill and having a rough alignment. The base was concealed, but just above the top of the outlier were a number of Mississippian bowlders, and on the north, west, and south at higher and lower levels are outcrops of the Jefferson City formation[1] (Fig. 2).

The summit of the ridge is capped by a thin stratum of Pennsylvanian sandstone, and bowlders of Pennsylvanian float are found in abundance at lower levels. The Pennsylvanian rests unconformably upon the Jefferson City formation on the east side of the hill. On the west side there appears to be a thin stratum of Mississippian between them, but the exposures are very poor, and the exact relationships are difficult to determine. The areal distribution of these rocks is shown on the map[2] (Fig. 2).

An excavation was made along the side of these quartzite masses in an attempt to expose the lower contact. This was not entirely successful, but the excavation showed that there was a continuous ledge of quartzite at least thirty feet long and from three to six feet in thickness, increasing in thickness toward the east. Beyond the limits of the excavation there are a few other knobs of quartzite, probably continuous with the part just described. This makes the total length of the outlier about fifty feet, and its greatest width slightly less. It is entirely confined to the little nose between the two gullies, and none has been found on neighboring hillsides. Bedding is indistinct, but there are indications of an eastward dip of about 15°. This is regarded as

[1] The Jefferson City beds exposed on this hillside are among the youngest known in this area. They consist of yellow earthy dolomites (cotton rock) interbedded with chert layers, which are often abundantly fossiliferous, a condition not observed in the lower beds of the same formation in the Rolla area. The fossils consist entirely of one or two species of *Hormotoma*, closely allied to *H. artemesia*. It is quite probable that these upper beds belong to the Cotter formation, which overlies the Jefferson City in the southern portion of the uplift, but which has not been recognized in this area. This cannot be definitely stated, however, until the Cotter and its contained fauna are more completely described.

[2] The writers are greatly indebted to Major C. E. Cooke, professor of topographical engineering in the department of vocational education, and his students, Messrs. Kimball and Hazlewood for making the topographic base for this map.

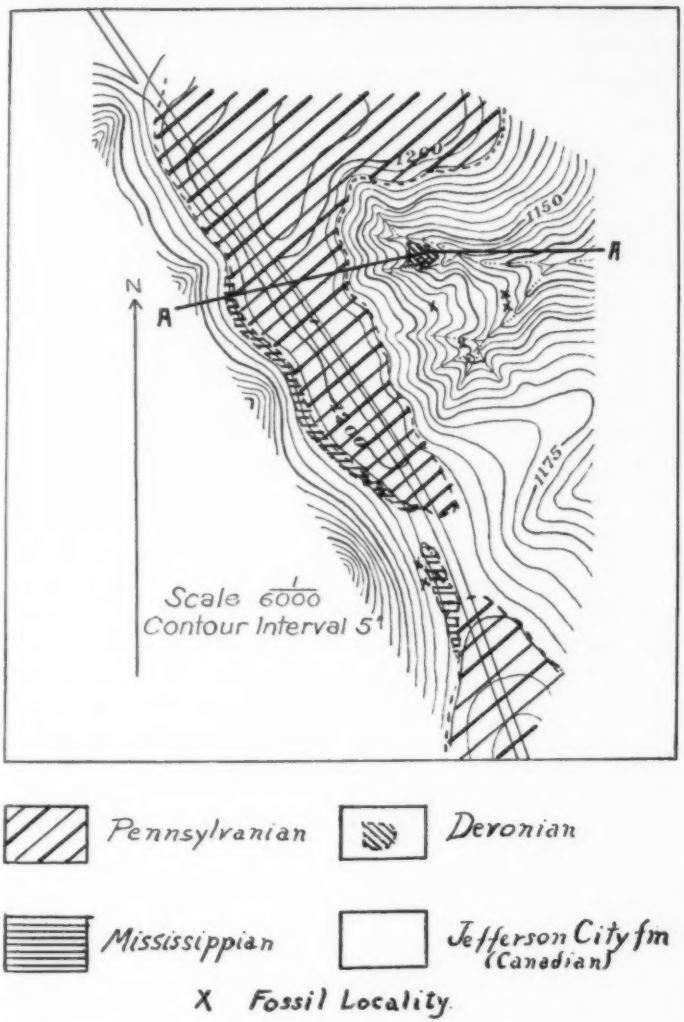

FIG. 2.—Geologic map showing the relationship of the Devonian to the older and younger rocks.

initial dip, and the entire mass appears to rest against an old eastward facing slope developed on the Jefferson City dolomite in a post-Beekmantown pre-Onondaga erosion interval (Fig. 3).

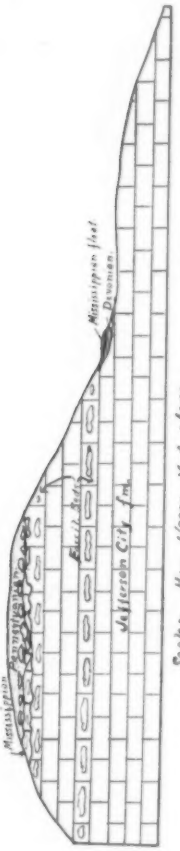

FIG. 3.—Structure section on the line A–A of Figure 2

The Jefferson City formation has been found outcropping to within ten feet of the summit of the hill on the east side and to within fifteen or twenty feet of the summit on the west side. Overlying the Jefferson City beds on the west side is a layer of large bowlders containing a typical Burlington fauna. This layer is continuous for several hundred feet, and the bowlders are quite large, and it seems altogether probable that they are in place, or that they have not been moved far from their original location. On the east side of the hill this layer is not as prominent, but bowlders of Mississippian and Pennsylvanian float are abundant all over the hillside, and some of them rest directly upon the Devonian.

LITHOLOGIC CHARACTERISTICS

Lithologically the Devonian rock is a hard, dense quartzite breaking with a splintery fracture. In color it ranges from white through gray to bluish and almost black. The lighter shades predominate. Thin sections show great numbers of well-rounded quartz nuclei with strong evidences of secondary growth. In some sections the grains show as angular interlocking crystals because of this secondary growth; in other sections, large secondarily enlarged grains are separated from each other by a finely crystalline ground mass of the same material. The rock contains numerous cavities, most of which have been formed by the leaching out of large fossils, and on the surfaces of these cavities are to be found many small but perfect crystals of quartz and of limonite

pseudomorphous after pyrite. The quartzite is somewhat fractured, and these fractures are filled with a soft, yellow, nonfossiliferous, somewhat conglomeratic sandstone.

From the structure and secondary growth it seems evident that the rock was originally a calcareous sandstone, laid down by an advancing sea against an old land mass. The calcareous matter has been completely leached out, and much of it replaced by silica. The soft, yellow sandstone is of later age, either basal Mississippian or Pennsylvanian.

PALEONTOLOGY

Fossils are abundant in the quartzite. They are not evenly distributed, but are most abundant at the base. At first glance, parts of the stratum appear to be barren, but careful search of almost any fragment will reveal fossils. The fossils all occur as external and internal molds, and in most cases the preservation is excellent. Corals and Mollusca dominate the fauna. Other forms are not common, though individuals of a given species may be very abundant.

The following table gives a list of the species which have been obained from this quartzite, and also their occurrence at other localities. Column 1 shows species occurring in the Grand Tower formation in southern Illinois; column 2, species occurring in the Jeffersonville beds at Louisville, Kentucky; column 3, species occurring in Michigan; column 4, species occurring in Ohio; and column 5, species occurring in New York.[1]

[1] Faunal lists:

1. Illinois: S. Weller, "Correlation of the Devonian Faunas in Southern Illinois," *Jour. Geol.*, Vol. V (1897), pp. 625–35.

T. E. Savage, "The Grand Tower (Onondaga) Formation of Illinois and Its Relation to the Jeffersonville Beds of Indiana," *Trans. Ill. Acad. Sci.*, Vol. III (1910).

2. Indiana, Kentucky: E. M. Kindle, "The Devonian Fossils and Stratigraphy of Indiana," *Ind. Dept. of Geol. and Nat. Res., Twenty-fifth Ann. Rept.* (1900), pp. 529–758.

H. Nettleroth, *Kentucky Fossil Shells.* Monograph, Kentucky Geological Survey, 1889.

W. J. Davis, *Kentucky Fossil Corals.* Monograph, Kentucky Geological Survey, 1885.

3. Michigan: C. Rominger, *Geol. Surv. Mich.*, Vol. III, 1876.

4. Ohio: F. B. Meek, *Pal. Ohio*, Vol. I, 1873.

H. A. Nicholson, *ibid.*, Vol. II, 1875.

5. New York: James Hall, *Paleontology of New York*, Vol. IV, 1867, and Vol. V, Part II, 1879.

General: Grabau and Shimer, *North American Index Fossils*, 1910.

TABLE I

LIST OF SPECIES IDENTIFIED FROM THE DEVONIAN QUARTZITE AT ROLLA, MISSOURI

	[1] Illinois	[2] Kentucky	[3] Michigan	[4] Ohio	[5] New York
Coelenterata:					
Zaphrentis gigantea, Lesueur	.....	x	x	x	x
Zaphrentis prolifica, Billings	.....	x	x	x	.....
Zaphrentis Sp	.....	.....	.....	.....	.....
Acervularia rugosa (E. and H.)	x	x	x	.....	.....
Amplexus yandelli (E. and H.)	x	x	x	.....	.....
Favosites winchelli, Rominger	.....	x	x	.....	x
Favosites emmonsi, Rominger	x	x	x	.....	.....
Favosites basalticus, Goldfuss	.....	.....	.....	x	x
Favosites turbinatus (?) Billings	.....	x	x	x	x
Favosites limitaris, Rominger	.....	x	x	.....	x
Favosites clausus, Rominger	.....	x	x	.....	x
Cladopora labiosa (Billings)	.....	x	x	.....	x
Molluscoidea:					
Cystodictya gilberti (?) Meek	x	H*	.....	x	.....
Stropheodonta demissa (Conrad)	x	x	?	.....	x
Rhipidomella vanuxemi, Hall	x	x	x	x	x
Centronella glansfagea, Hall	x	x	x	x	x
Eunella (?) *Sp*	.....	.....	.....	.....	.....
Spirifer divaricatus, Hall	.....	x	.....	x	x
Spirifer grieri (?), Hall	x	x	.....	x	x
Martinia maia (?) (Billings)	.....	.....	.....	x	.....
Nucleospira concinna, Hall	x	x	.....	x	x
Mollusca:					
Actinodesma occidentale (?), Hall	x	x	.....	.....	.....
Conocardium cuneus (Conrad)	x	var.	.....	x	x
Conocardium ohioense, Meek	.....	x	.....	x	.....
Bellerophon pelops, Hall	x	x	.....	x	x
Bellerophon newberryi, Meek	.....	.....	.....	x	?
Hormoloma maia, Hall	.....	.....	.....	.....	.....
Igoceras conicum (Hall)	x	x	.....	x	x
Loxonema robustum (?), Hall	.....	.....	.....	x	.....
Cyclonema crenulata, Meek	.....	x	.....	x	.....
Callonema bellatula, Hall	.....	x	x	x	.....
Callonema humile, Meek	.....	x	.....	x	.....
Callonema conus, Kindle	.....	x	.....	.....	.....
Tentaculites scalariformis, Hall	x	x	.....	x	x
Coleolus tenuicinctum, Hall	x	.....	.....	H	H
Orthoceras Sp	.....	.....	.....	.....	.....
Gomphoceras Sp (2)	.....	.....	.....	.....	.....
Zittleoceras nereus, Hall	.....	.....	.....	.....	x
Arthropoda:					
Phacops cristata, Hall	x	x	.....	.....	x
Proetus clarus, Hall	x	x	.....	.....	.....
Dalmanites calypso, Hall	x	x	.....	x	x

*H indicates that species occurs in the Hamilton at that particular locality.

CORRELATION

From the foregoing table it is evident that this fauna is of Onondaga age, and that it is the partial equivalent of the Grand Tower formation of southern Illinois and southeastern Missouri. Its affinities are entirely with the eastern Devonian and have no resemblance to the later Devonian faunas of Iowa and north central Missouri. Of the thirty-seven identified forms, seventeen occur in the Grand Tower formation of southern Illinois, thirty in the Jeffersonville beds of southern Indiana, thirteen in the Onondaga group of Michigan, twenty-two in the Onondaga of Ohio and eighteen in the Onondaga of New York. These figures are not exact and are probably too low, for the faunal lists from the various regions are incomplete and represent compilations in most cases. The most complete lists are those from the Grand Tower formation and from the Jeffersonville beds. Weller[1] and Savage[2] have shown the relationship of the Grand Tower fauna to the Onondaga of the eastern United States.

Savage[3] has also shown that the Jeffersonville beds are the equivalent of the upper portion of the Grand Tower of Illinois. Since more than 80 per cent of the forms occurring at Rolla are also found in the Jeffersonville beds, it seems certain that this outlier belongs to the upper portion of the Grand Tower formation. In Ste. Genevieve County, Missouri, Weller[4] assigns over two hundred feet of strata to the Grand Tower formation. Certain horizons in this formation are reported to be full of corals, but until the faunal lists for this formation are completed, a closer correlation cannot be made.

CONCLUSIONS

The presence of a Grand Tower outlier at Rolla indicates a much greater submergence of the Ozark uplift during Onondaga time than has commonly been supposed. The nearest outcrops of the Grand Tower formation are at least 100 miles to the east. The

[1] S. Weller, *loc. cit.*

[2] T. E. Savage, *loc. cit.* [3] *Ibid.*

[4] Stuart Weller, unpublished manuscript on Ste. Genevieve County, Missouri, Missouri Bureau of Geology and Mines.

St. Francois Mountains, the structural center of the uplift, are directly between the two exposures, and it is not believed that these were covered in Devonian time. In view of the thinning out of the Devonian to the north, it may be assumed that the Onondaga sea extended westward along the southern border of the St. Francois Mountains, and that it may have covered much of the southern portion of the uplift. Further field work may reveal other outliers, which will enable the boundaries of this sea to be traced more definitely.

THE EARLY PRE-CAMBRIAN FORMATIONS OF NORTHERN ONTARIO AND NORTHERN MANITOBA

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The classification of rocks earlier than the Cambrian is one of the difficult problems of geology. Correlation from point to point rests largely upon lithology and upon the succession of lithological units, and difficulties arise both from original similarity of formations of quite different age, and from similarity through the developments of the same metamorphic minerals in rocks originally of quite different character. Correlation is especially difficult in formations of early pre-Cambrian time, since these have undergone much longer periods of deformation than have the later ones. Varying successions of these early rocks have been worked out in some detail in different parts of the Canadian shield, and many attempts have been made to formulate a generalized succession that will fit all areas. None of these attempts has been successful, since the determination of the age of a formation by its likeness to a certain formation as described in an accepted classification, is liable to lead to quite erroneous conclusions. A review of some areas in western Ontario and northern Manitoba will show the diversity in various sections and will, it is believed, make possible certain generalizations.

RAINY LAKE DISTRICT

The first attempt to subdivide the early complex was made by Lawson[1] in the Rainy River district. He recognized two formations earlier than the first granite intrusion. The lower of these is his *Coutchiching series*, which he believes to be the oldest formation in the area. The Coutchiching rocks consist of mica

[1] *Geol. Survey of Canada, Ann. Rept.*, New Series, Vol. III, Part I (1887–88).

DISTRICTS

Rainy Lake	1
Porcupine	2
Abitibi	3
Lake Nipigon	4
NW. Manitoba	5
Wekusko L.	6
Cross Lake	7
Knee Lake	8

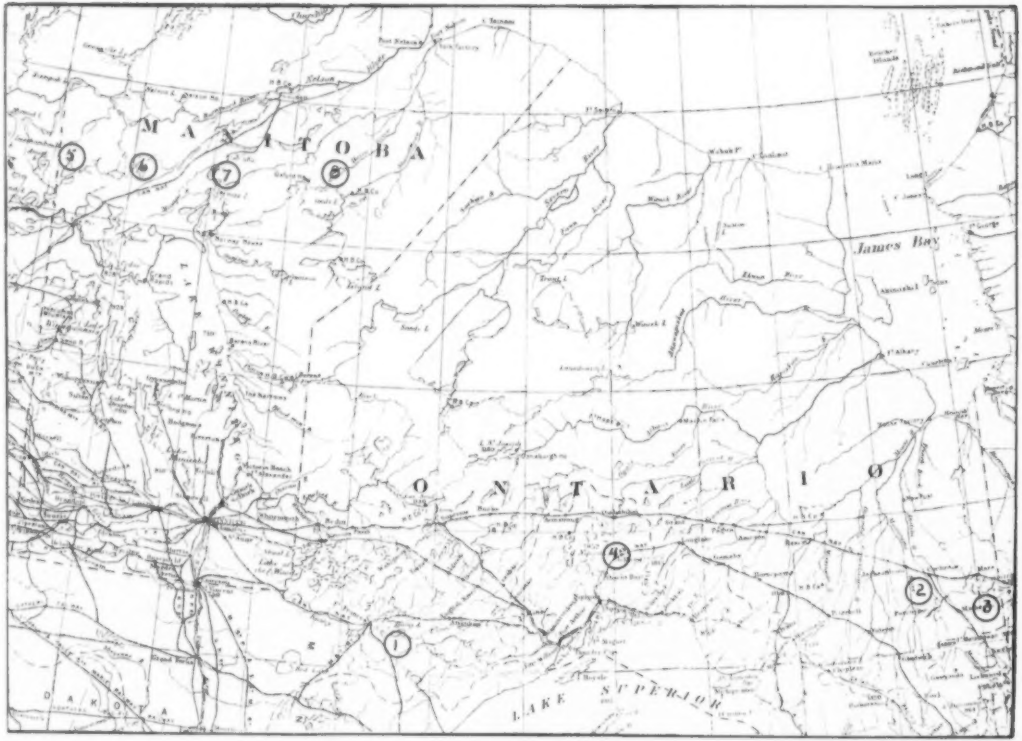

FIG 1

schists, garnetiferous mica schists, hornblende schists, and phyllite.[1] In some of the mica schist, quartz makes up three-fifths of the rock mass, biotite one-fifth, with zoisite the other important mineral present. It seems evident from Lawson's descriptions of the field occurrences and from the results of petrographical examinations and chemical analyses as given in his report, that the rocks are sediments, possibly of somewhat abnormal types. They are entirely clastic; no limestones have been found in association with them. A striking and peculiar circumstance is the lack of coarse sediments or conglomeratic beds in this supposedly thick series. It seems possible that these rocks were formed along the seaward margin of a delta which supplied large quantities of fairly fine débris, the site of deposition for the Coutchiching being so far from shore that no gravels were supplied, but not far enough out to allow the formation of limestones, assuming that conditions were suitable for the deposition of lime rocks at that early period.

The *Keewatin series* consists of: "(1) fine-grained greenstones showing frequently ellipsoidal or amygdaloidal structures or both; (2) coarser-textured greenstones showing neither ellipsoidal nor amygdaloidal structures; (3) greenstone schists of varying degrees of schistosity; (4) rather massive chlorite schists; (5) evenly fissile chlorite schists; (6) irregularly cleaved chlorite schists; (7) black glistening hornblende schists usually on the periphery of the Keewatin belts where they come in contact with granitic intrusions; (8) gray felsite sometimes amygdaloidal; (9) sericitic schists; (10) various stratified grayish-green schists, probably ash beds; (11) agglomerates; (12) gray siliceous slates and schist; (13) banded cherts; (14) mica schists; (15) limestone."[2]

This group is clearly made up for the most part of lava flows and their derivatives with minor amounts of sediments interbanded with the igneous rocks. In summary, then, it may be said that the Coutchiching consists chiefly of sediments, with possibly some beds, such as the hornblende schists, of igneous origin; the Keewatin series is chiefly igneous, with minor sedimentary beds intercalated with the lava flows. There seems

[1] Lawson, *Memoir 40, Geol. Survey of Canada*, p. 28.

[2] *Ibid.*, p. 35.

to have been no erosion period between the formation of the two series.

Lawson considered the Coutchiching to be a distinct series underneath the Keewatin, but the international committee to revise the classification of pre-Cambrian formations did not agree. In some of the areas examined rocks mapped as Coutchiching in the original work were found to belong to the Seine series, which lies with a great unconformity above the Keewatin. Mistakes of this kind are quite to be expected in determining somewhat similar series under the difficult conditions of the original mapping. Lawson, in his later publication, *Memoir 40, Geological Survey of Canada*, admits these mistakes, but still maintains that there is a great sedimentary series below the Keewatin. Some competent observers who have visited the area agree with him.[1] The point has also been raised that the Coutchiching may not be the oldest formation, but may be similar to the interbedded sediments—(12) in the Keewatin—and that beneath the Coutchiching again there may be still older lava flows. If so, it is argued, the Coutchiching series may quite logically be included as part of the Keewatin.

PORCUPINE DISTRICT

The earliest rocks in the Porcupine district of northern Ontario consist of pillow lavas with schists derived from them, "carbonate" rocks of doubtful origin, iron formation, and some fragmental rocks of doubtful character.[2] A group of undoubtedly sedimentary rocks is correlated by Burrows with the Temiskaming series. They consist of "conglomerate, interbanded slate and greywacké, and quartzite." The relations of these sediments to the Keewatin group are shown by the following quotations:

> A contact of the sedimentary rocks with the volcanic rocks can be seen immediately south of the open pit at the Dome mine. Fragments of the volcanic series are abundant in the sedimentary series, and it is likely that the conglomerate has been deposited on the surface of the volcanic series of the Keewatin. . . . . However, one half a mile north west of the north end of

[1] Private Communications, F. J. Alcock and T. L. Tanton.

[2] A. G. Burrows, "The Porcupine Gold Area," *Third Ann. Rept. Ont. Bureau of Mines*, Vol. XXIV, Part III (1915).

Porcupine lake in lot 11 in the fourth concession of Whitney there is a contact of the sedimentary series with pillow lava in which the relationship suggests an igneous contact, that is that the pillow lava is later than the sedimentary rock. It is therefore probable that some of the pillow lavas mapped with the Keewatin are later in age than the Temiskaming series.

While there is much evidence pointing to a separate sedimentary series of rocks the possibility of some of what has been called Keewatin being contemporaneous with the Temiskaming or of some of the sediments being of Grenville age must be considered. Toward the southwest from the open pit at the Dome mine there is a narrow band of conglomerate which has been mapped at Temiskaming. Much of the material in this band immediately north of the readily recognized pillow lava and amygdaloidal rock resembles volcanic fragmental or agglomerate. There is no break, however, between the apparent volcanic fragmental and the interbedded slate and greywacke which occur along the south margin of the open pit and which can be followed northward for a mile. If the rock above mentioned is a volcanic fragmental, and not a true conglomerate deposited on an eroded surface, then there is reason for considering the pillow lavas, fragmental rocks, slates, greywacké and conglomerate as belonging to one series. For lithological reasons it seems preferable to consider the large area of sediments as a separate series.

It is apparent that Burrows recognized the possibility of an interbedded series of sediments and volcanics, but that he decided to correlate the sedimentary part of the series with the lithologically similar Temiskaming rather than accept an alternative hypothesis of a great continuous series made up of lava flows, volcanic fragmentals, and true sediments. The evidence for an erosional unconformity between the volcanics and sediments does not seem to be conclusive.

ABITIBI DISTRICT

The district south of Lake Abitibi has recently received considerable attention, and an interesting series of rocks has been found.[1] Lava flows which are classed as Keewatin are exceptionally well developed, and the scoriaceous surfaces of successive flows make it possible to determine the top and bottom of the formations. Sediments are associated with these lavas. The following is a quotation from the report mentioned:

[1] C. W. Knight, A. G. Burrows, P. E. Hopkins, and A. L. Parsons, "Abitibi Night Hawk Gold Area," *Eighteenth Ann. Rept. Ont. Bureau of Mines*, Part II (1919).

In our map sheet there is an interesting series comprised of highly altered sediments which are closely associated with the Keewatin. . . . . One belt has an apparent thickness of one and one half miles and a length of 11 miles. . . . .

The rocks in the three large areas mentioned in the preceding paragraph consist of slate, greywacké, quartzite, and a little conglomerate, all of which have been altered to schists. Both the cleavage and bedding of the sediments have nearly vertical dips, but there are usually small angles between their strikes. A little chert is also present. Conglomerate schist was seen in four localities and, in each case, near the outer edge of the sediments. . . . . The pebbles which are somewhat flattened, consist of quartz porphyry and greenstones, suggesting an unconformity between the sediments, on the one hand, and the greenstones and quartz porphyry on the other. However, the only good contacts which were seen between the sediments and the greenstones were on lot 7 in the second concession of Coulson township and these might suggest that the sediments were interbedded with the pillow lavas of the Keewatin. It may be added that in this locality the banded cherts which appear to be a part of the main group of sediments are older than the pillow lavas. In view of these apparently conflicting observations it is seen that the relationship between the Keewatin lavas and these old sedimentary rocks has not been definitely worked out. Possibly the conglomerates may be of interformational origin or may belong to the Temiskaming series.

It seems clear that there are two possibilities. Either the lava flows here called Keewatin are in reality much younger than those usually classed as Keewatin, younger in fact than the Temiskaming series, or there is a great interbanded series of lava flows, tuffs, and sediments. The presence of conglomerate in such a series is quite to be expected.

LAKE NIPIGON DISTRICT

In the Kowkash area east of Lake Nipigon, Hopkins[1] has found a series of rocks which he calls the Marshall Lake series. This group consists of quartz-mica schists, garnet, and staurolite schists. Hopkins says:

The chemical composition, microscopic evidence, and frequent occurrence of alternating coarse and fine bands in these quartzose rocks suggest that they are clastics or volcanic fragmental rocks deposited in water. Since they are interbanded with ellipsoidal lavas on Cross lake and contain some iron formation they are apparently closely associated with the Keewatin.

[1] *Ann. Rept. Ont. Bureau of Mines*, Vol. XXVI (1917), p. 206.

No evidence is given for considering these rocks as volcanic fragmental types, and judging from the description they seem to be normal fine-grained clastic sediments.

Along the Canadian Northern Railway east of Lake Nipigon,[1] Burrows found a complex of igneous and clastic rocks, all of which he grouped tentatively as Keewatin. Concerning them he says:

> The age relationship between the mica and quartzose schists of sedimentary origin and the pillow lavas and other igneous rocks is not known. For the most part the sedimentary rocks stand so nearly in a vertical attitude that their relationship cannot be determined. It seems advisable to group all these rocks with the Keewatin until information is available to show that the sedimentary rocks may possibly be older than the lavas.[2]

Both Burrows and Hopkins classify certain other conglomerate rocks as Temiskamian, but in neither area are the conglomerates found definitely unconformable with the lavas. The correlation is a lithological one in both cases, the later age being assumed from the presence of pebbles of jasper, greenstone, and granite in the conglomerate beds.

PRE-CAMBRIAN SECTIONS IN MANITOBA

Various sections in northern Manitoba have been examined in some detail, and a strip of country extending almost across the province has been mapped. Beginning at the Saskatchewan boundary, where the pre-Cambrian basement emerges from beneath the Paleozoics, a series of three map sheets extends eastward to the Hudson's Bay Railway. Northeast of Lake Winnipeg two areas—the Cross Lake district and the Knee-Oxford Lake district—have been studied.

In the most westerly section the oldest rocks are ellipsoidal greenstone and derived schists.[3] Supposedly later than these is a thick series known as the Kisseynew gneiss, a garnetiferous, quartz-biotite gneiss apparently sedimentary in origin. There is also a group of slates, quartzites, and conglomerates. The latter are quite evidently the result of torrential deposition probably in

[1] *Ann. Rept. Ont. Bureau of Mines*, Vol. XXVI (1917), p. 232.

[2] *Ibid.*, p. 239.

[3] *Mem. 105, Geol. Survey of Canada.*

river flood plains. This group, the lower and upper Missi formations, are, however, on structural evidence, thought to be separated by a mountain-making and erosional interval from the volcanic rocks and are therefore not considered in this discussion of the early pre-Cambrian formations.

In the Wekusko (Herb) Lake district, approximately seventy-five miles east of the Saskatchewan-Manitoba boundary, ellipsoidal lavas occur which are apparently the continuation, so far as lavas can be continuous, of the area just described. They are lithologically similar and outcrop practically continuously across the interval. Quartz-biotite gneisses lithologically similar to the Kisseynew gneiss are associated with them. Staurolite schist, conglomerate, slate, and acid volcanic flows also occur. All these are interbanded with the basic ellipsoidal flows.

Alcock's summary[1] is very definite with regard to the relations and character of these early rocks:

> The pre-granite complex is interpreted, therefore, as representing a series of interbanded sediments and volcanic rocks of varying composition. Though the sedimentary division contains members which have pebbles of granite, quartz, and volcanic rocks, no evidence was found that these pebbles were derived from any rocks now exposed in the area, nor was any evidence found, aside from the presence of these bowlders and pebbles, which would suggest that the members containing these fragments represent a younger series infolded with the complex and separated from it by an erosional unconformity. The whole group is regarded as a series of flows and contemporaneous sediments. The absence of limestone, the dominance of clastic sediments, the irregularity of the beds, the great thicknesses locally, the recurrence of conglomeratic horizons, point to a continental rather than to a marine origin for the series.[2]

At Cross Lake, an expansion of the Nelson River below Lake Winnipeg, a series of sedimentary rocks consists of para-gneiss, arkose, and conglomerate; some of the gneisses are garnetiferous. Greenstone, which in places is ellipsoidal, occurs in the area. The sediments are interbanded with the lavas. They are interpreted as continental, probably fluviatile deposits.[3]

[1] F. J. Alcock, *Memoir 119, Geol. Survey of Canada.*

[2] *Ibid.*, p. 24.

[3] F. J. Alcock, *Summary Report, Geol. Survey of Canada*, Part D (1919).

Eastward across the divide on the headwaters of the Hayes River, early pre-Cambrian rocks are exposed at Knee Lake and Oxford Lake.[1] A lower, dominantly sedimentary part, consists of rusty weathering garnetiferous biotite gneiss, impure quartzite, slate, conglomerate, tuffaceous rocks, and some interbedded flows. The thickness is probably several thousand feet. Above the dominantly sedimentary group are flows of ellipsoidal weathering lavas together with a few bands of iron formation. These groups are apparently merely parts of a great continuous series. The sediments are in great part typical continental deposits.

COMPARISON OF THE FORMATIONS

From the descriptions of the various areas quoted it is clear that there are two distinct types of rocks in the early formations: (1) volcanic flows now altered to greenstone and chlorite schist, and (2) sedimentary rocks consisting largely of gneiss but also in places including slate, quartzite, and minor amounts of conglomerate. The gneisses retain evidences of bedding although in many occurrences metamorphism has destroyed some of the original texture. Analyses of specimens of these old gneisses are comparable to analyses of typical sediments. The slates commonly show the original bedding as color variations at slight angles to the fissility. Some arkosic rocks still retain the cross bedding and ripple-markings of the original sands and conglomerate, even though the matrix may be thoroughly schistose, with complete recrystallization of the constituent minerals, and are still recognizable as water-laid clastic rocks.

The peculiarities of all the sedimentary formations of this early period are the comparatively small amount of conglomerate and the complete lack of limestone. The sediments found in Manitoba are continental deposits probably formed under deltaic or piedmont conditions. The lack of any large amount of coarse material is evidence that no high land masses existed near the site of deposition, but the ripple-marking and cross-bedding of some of the rocks indicate shallow-water conditions during the formation of some of the beds. The early sediments in other areas

[1] E. L. Bruce, *Summary Report, Geol. Survey of Canada*, Part D (1919).

are similar to those in Manitoba, and it may be assumed that they were formed in much the same way.

The volcanic rocks are lithologically similar throughout the whole region discussed, and this striking similarity quite naturally has led to the correlation of these rocks wherever they occur. The flows are ellipsoidal or massive greenstone of medium basicity. Many of them are now altered to schists. Along with these, minor thicknesses of acidic flows and tuffaceous beds occur. In many districts thin sedimentary beds are found with the igneous rocks. Banded iron formation is very commonly associated with the flows of basic composition.

Although the rock types are comparable, the age relations are variable. In some districts the sedimentary rocks lie above the volcanics. In others the two are interbanded, and in others the greater thickness lies below the igneous rocks. No erosion interval has been recognized; the separation into igneous and sedimentary divisions made in some localities, is purely arbitrary, and implies simply that the divisions are dominantly clastic or dominantly igneous. For in most occurrences there are sedimentary beds among the igneous rocks and flows intercalated with the sediments.

CLASSIFICATION

None of the general classifications of pre-Cambrian formations is applicable to this early complex. The classification[1] accepted by the International Committee places the Keewatin as the lowest formation and does not recognize the presence of great thicknesses of clastic sediments below the great unconformity at the base of the Huronian, nor Lawson's Coutchiching as a great series below the igneous flows. There are, however, not only in the Rainy River district, but in other districts, thick sedimentary formations below the oldest lava flows recognized in those districts. It is possible, as suggested, that other older lava flows exist beneath the sediments, but if so, the application of the term Keewatin, if it is to be retained, must be extended to include a large amount of sedimentary rocks.

[1] *Jour. of Geol.*, Vol. XIII (1905), pp. 89–104.

On the other hand, the original classification suggested by Lawson, in which the sedimentary Coutchiching is the oldest formation, cannot be applied to those successions in which the sediments are interbanded with lava flows or even lie above rocks which are lithologically similar to the Keewatin.

From theoretical considerations it seems unlikely that any of these formations can be used to correlate successions in different districts. Commonly the basic flows have been used in this way. Since they are lavas, it is impossible that any one eruption could have extended to any great distance, and hence correlation on the basis of lithology of separate flows must be most uncertain. Nor is this affected by the possibility that many of the flows are subaqueous, as there is no evidence that the bodies of water beneath which the flows may have been extruded were large or continuous. In fact, in some instances the interbedding of ellipsoidal flows and shallow water or terrestrial sediments is evidence that the bodies of water were limited in area and of brief duration. Correlation by means of the sedimentary beds is even less reliable. The conglomerate, slate, and gneiss of this early period are believed to be almost entirely of terrestrial or shallow-water origin. No bed formed in this way could be expected to have great lateral extent, and no determination of age can be made on the ground of its similarity to rocks in other districts.

Since no erosion break has been recognized in any of the successions yet worked out, and since there is this very marked difference in the relations of sedimentary and igneous rocks in various areas, it is plain that no course is possible, at present, except the interpretation of the early part of the pre-Cambrian as a period of volcanic activity in which eruptions of lava alternated with deposition of ordinary clastic sediments. These periods of eruption were recurrent, but not necessarily contemporaneous even in neighboring districts. Hence the succession of volcanic and sedimentary rocks is naturally not the same in any two districts. The result is a great thickness of lavas, tuffs, and sediments, all of which belong to one great period in the earth's history. It is manifestly impossible to apply to rocks of such origin either of the terms Keewatin or Coutchiching and, if the view set forth here be

accepted, it seems necessary to restrict those terms to the original area in which they were applied. If it seems convenient in any other area to divide the rocks of this early period, local names should be applied to the divisions without implying any wide regional correlation. Detailed examination may later make clear the time relations of events, and if so, correlations can then be made. If that ever becomes possible, it seems more than likely that instead of rocks of similar lithology being found to belong to the same period, it will be found that flows in some districts are contemporaneous with sediments in others, or that a period of deposition of sediments in one section corresponds to a period of local erosion in a neighboring section.

Although at present sufficient work has not been done to make correlation possible, it is interesting to note the distribution of the sediments in relation to the igneous rocks. In western Manitoba the sediments lie above the flows. In north central Manitoba flows and sediments are interbedded. In eastern Manitoba and western Ontario the great mass of sediments lies beneath the volcanics. In eastern Ontario the two are again interbedded. These relations can be explained by the presence of a great area of continental deposition extending southward from an old land mass in central Canada in the very earliest times. Over this area, terrestrial and shallow-water deposits were laid down on river plains, piedmont fans, or deltas along whose margin sediments were interbedded with subaqueous lava flows. Still farther out no sediments at all were deposited until a later readjustment of land and water shifted the zone of sedimentation to areas where, previously, only igneous rocks were forming. At the same time the central area became the site of igneous activity and the extrusion of lavas over the clastic sediments already laid down. At present this can be considered only a suggestion resting upon slight field evidence.

SUMMARY

The points raised in the preceding discussion can be settled only by more detailed work, but the following conclusions seem to be warranted from present knowledge:

1. In the early part of the pre-Cambrian, periods of volcanic activity alternated with periods of normal sedimentation. The resulting rocks form one great series.

2. At present local terms only should be used in subdividing this complex. The terms now in use in the generalized classifications are inapplicable, and should be restricted to the areas in which they were used originally.

3. The sedimentary record of the early pre-Cambrian seems to be largely one of continental rather than marine conditions. Some of the deposits were undoubtedly deltaic, others were likely piedmont, lacustrine, fluviatile, and even basin deposits. It points to the conclusion that even from the very earliest pre-Cambrian, the Canadian shield was a positive element.

THE TIME OF GLACIAL LOESS ACCUMULATION IN ITS RELATION TO THE CLIMATIC IMPLICATIONS OF THE GREAT LOESS DEPOSITS: DID THEY CHIEFLY ACCUMULATE DURING GLACIAL RETREAT?

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Although deposits similar in several respects to glacial loess are forming today near the borders of certain deserts and along the bluffs of some great rivers, the widespread, thick loess deposits which are associated with some drift sheets imply peculiar climatic conditions, for no deserts are now close to these ancient deposits, and parts of them are far from great rivers. There have been many discussions of the probable origin of loess, and thus, indirectly, of its climatic implications. Much has been learned, among other things that different deposits accumulated under different conditions. But one question appears not to have been satisfactorily settled, that is, At what time, in respect to glaciation, did the greater part of the accumulation take place? Several American and European students have thought that the great loess deposits date from interglacial times. On the other hand, Penck has concluded that the loess was formed shortly before the commencement of the glacial epochs; while many American geologists have held that most of the loess accumulated while the ice sheets were at approximately their maximum size. Chamberlin and Salisbury,[1] McGee, and others lean toward this view.

There is evidence in support of each of these hypotheses, but it seems well to reconsider the possibilities that a large share of the great deposits associated with glaciation were formed at the one other possible glacial time, namely immediately following the retreat of the ice. Recent evidence affords light not available to the workers

[1]Chamberlin and Salisbury, *Geology*, Vol. III (1906), pp. 405–12, a comprehensive discussion of the characteristics and distribution of the American loess, with references to McGee, Shimek, and others.

years ago when the origin of the loess was under heated discussion. Furthermore, the emphasis in the past has been on the agencies of deposition rather than on the time of deposition. Indeed the latter question does not seem to have received much consideration, in spite of its importance in the interpreting of the climatic conditions during a part of the past.

These four hypotheses as to the time of origin of loess imply differences in its climatic relations. If loess was chiefly formed during typical interglacial epochs, or toward the close of such epochs, profound general aridity must seemingly have prevailed in order to kill the vegetation and thus enable the wind to pick up sufficient dust. If the loess was chiefly formed during times of extreme glaciation when the glaciers were supplying large quantities of fine material to out-flowing streams, less aridity would be required, but seemingly there must have been sharp contrasts between wet seasons in summer when the snow was melting and dry seasons in winter. Alternate floods and droughts would thus affect broad areas along the streams. Hence arises the hypothesis that the wind obtained the loess from the flood plains of streams at times of maximum glaciation. If the loess was chiefly formed during the rapid retreat of the ice, alternate summer floods and winter droughts would still prevail, but much material could also be obtained by the winds, not only from flood plains, but also from the deposits exposed by the melting of the ice and not yet covered by vegetation.

In support of the hypothesis of the interglacial origin of loess, Shimek and others state that the glacial drift which lies beneath the loess commonly gives evidence that some time elapsed between the disappearance of the ice and the deposition of the loess. For example, most of the locally abundant shells of snails in the loess are not of the sort now found in colder regions, but resemble those found in the drier regions. It is probable, Shimek concludes, that if they represented a glacial epoch all would be dwarfed by the cold as are the snails of far northern regions. The gravel pavements, discussed below, are pointed out by Shimek as strong evidence of erosion between the retreat of the ice and the deposition of the loess.

Turning to the second hypothesis, namely that the loess accumulated near the close of the interglacial epoch rather than in the

midst of it, we may follow Penck.[1] The mammalian fossils seem to him to prove that the loess was formed while boreal animals occupied the region, for they include remains of the hairy mammoth, woolly rhinoceros, and reindeer. On the other hand, the typical interglacial beds not far away yield remains of species characteristic of milder climates, such as the elephant, the smaller rhinoceros, and the deer. In connection with these facts it should be noted that occasional remains of tundra vegetation and of trees are found beneath the loess, while in the loess itself certain steppe animals, such as the common gopher, or spermaphyl, are found. Penck interprets this as indicating a progressive desiccation culminating just before the oncoming of the next ice sheet.

The evidence in favor of the hypothesis that the loess was formed during the maximum extension of the ice chiefly concerns its relation to the ice sheets and to the streams which flowed from the melting ice. If the great American deposits of loess do not represent the outwash from the Iowan ice, there is little else that does, and presumably there must have been outwash. Also the distribution of loess along the margins of streams suggests that much of the material came from the flood plains of overloaded streams flowing from the melting ice. Furthermore, in many places at least, the drift just beneath the loess presents little or no evidence of having been weathered or leached before the loess was laid down. Chamberlin found that many tests showed it to contain about as much calcareous material as the loess itself. This suggests that it was laid down at about the same time as the underlying drift, not notably afterward.[2] Likewise, although Shimek has emphasized the fact that most of the snails do not show depauperization, McGee reports that depauperization is evident among those found near the glacial margins, and that shells are very rare there. Both of these conditions suggest that much of the loess accumulated under glacial conditions.

Thus although there are some points in favor of the hypothesis that the loess originated (1) in strictly interglacial times, (2) at

[1] Penck's conclusions are given in full in W. B. Wright, *The Quarternary Ice Age*, London, 1913.

[2] T. C. Chamberlin, personal communication.

the end of the interglacial epochs, and (3) at times of full glaciation, each hypothesis is much weakened by evidence that supports the others. The evidence of boreal animals seems to disprove the hypothesis that the loess was formed in the middle of a mild interglacial epoch. On the other hand, Penck's hypothesis as to loess at the end of interglacial times fails to account for certain characteristics of the lowest part of the loess deposits and of the underlying drift. Instead of normal valleys and consequent prompt drainage, such as ought to have developed before the end of a long interglacial epoch, the surface on which the loess lies shows many undrained depressions. Some of these can be seen in exposed banks, while many more are inferred from the presence of shells of pond snails here and there in the overlying loess. The pond snails presumably lived in shallow pools occupying depressions in the uneven surface left by the ice. Another reason for questioning whether the loess was formed chiefly at the end of an interglacial epoch is that this hypothesis does not provide a reasonable origin for the material which composes the glacial loess deposits of important loess-covered regions. Near the Alps, where the loess deposits are small and where glaciers probably persisted in the interglacial epochs and thus supplied flood material in large quantities, this shortcoming perhaps does not appear important. In the broad Upper Mississippi basin, however, and also in the Black Earth region of Russia there would seem to be, during an interglacial epoch, no way to get the large body of material composing the loess, except by assuming the existence of great deserts to windward. But there is little or no evidence of such deserts where they could be effective. The mineralogical character of the loess of Iowan age proves that the material came from granitic rocks, such as formed a large part of the drift. The nearest extensive outcrops of granite are in the southwestern part of the United States, nearly a thousand miles from Iowa and Illinois. But the loess is thickest near the ice margins and thins toward the southwest and in other directions, whereas if its source was the southwestern desert its maximum thickness would probably be near the margin of the desert. Furthermore the similarity in calcareous content of the loess and the underlying drift, reported by Chamberlin, points

against Penck's hypothesis, for if the loess did not accumulate until near the close of an interglacial epoch, it is probable that the calcareous matter would have been largely leached from the upper layers of the underlying drift. The interglacial epochs are now known to have been sufficiently long for much weathering to take place. Thus considerable evidence seems inconsistent with the hypothesis that the loess was formed chiefly toward the close of an interglacial epoch.

There is much less evidence against the hypothesis that the great loess deposits accumulated chiefly during the maximum extension of the ice. Indeed it remains as a worthy working hypothesis. However, the question may be raised as to whether or not flood plains of streams would provide adequate supplies of materials for such widespread, rather uniform deposits as those of Russia and of Iowa and Illinois. A further question comes to mind: Would the type of vegetation which would probably occur along the ice front at its maximum extension be that of which the loess gives evidence? Indeed it seems probable that when the ice advanced, its front lay close to areas where the vegetation was not much thinner than that which today prevails under similar climatic conditions. If the average temperature of glacial maxima was only about 6°C. lower than that of today, as many authorities consider likely, the conditions just beyond the ice front when it was in the loess region from southern Indiana to Nebraska would probably have been like those now prevailing in Canada from New Brunswick to Winnipeg. The vegetation there is quite different from the grassy vegetation of which evidence is found in the loess. The roots and stalks of such grassy vegetation are generally agreed to have helped produce the columnar structure which enables the loess to stand with almost vertical surface. Thus it seems appropriate to add a supplementary hypothesis to suggest that certain phenomena would be readily explainable in case the chief accumulation was during glacial retreat, rather than at the time of maximum extension of ice.

We are now ready to consider the probability that loess accumulated mainly during the retreat of the ice. Such a retreat exposed a zone of drift to the out-blowing glacial winds. Most glacial hypotheses, such as that of uplift, or depleted carbon dioxide,

call for a gradual retreat of the ice scarcely faster than the vegetation could advance into the abandoned area. Under Huntington's solar-cyclonic hypothesis,[1] on the other hand, the climatic changes may have been sudden and hence the retreat of the ice may have been much more rapid than the advance of vegetation. Now wind-blown materials are derived from places where vegetation is scanty. Scanty vegetation on good soil, it is true, is usually due to aridity, but may also result because the time since the soil was exposed has not been long enough so that it may be covered with vegetation. Sand bars, mud flats, and flood plains are common examples. Moreover, violent winds and low temperatures may prevent the spread of vegetation. Thus it appears that unless the retreat of the ice were as slow as the advance of vegetation, a barren area of more or less width must have bordered the retreating ice and formed an ideal source of loess.

Several other lines of evidence seemingly support the conclusion that the loess was chiefly formed during the retreat of the ice. For example, Shimek, who has made almost a life-long study of the Iowan loess, emphasizes the fact that there is often an accumulation of stones and pebbles at its base. This suggests that the underlying till was eroded before the loess was deposited upon it. The first reaction of most students is to assume that of course this was due to running water. That is possible in many cases, but by no means in all. So widespread a sheet of gravel could not be deposited by streams without destroying the irregular basins and hollows of which we have seen evidence where the loess lies on glacial deposits. On the other hand, the wind is competent to produce a similar gravel pavement without destroying the old topography. "Desert pavements" are a notable feature in most deserts. The commonest winds are outward near the edge of an ice sheet, as Hobbs has made us realize.[2] They often attain a velocity of eighty miles an hour in Antarctica and Greenland.

[1] Ellsworth Huntington, *Earth and Sun*, Yale Press, New Haven, 1922; and Huntington and Visher, *Climatic Changes, Their Nature and Causes*, Yale Press, 1922.

[2] W. H. Hobbs, *Characteristics of Existing Glaciers*, 1911; "The Rôle of the Glacial Anti-Cyclone in the Air Circulation of the Globe," *Proceed. Am. Phil. Soc.*, Vol. LIV (1915), pp. 185–225.

Such winds, however, usually decline rapidly in velocity only a few score miles from the ice. Thus their effect would be to produce rapid erosion of the freshly bared surface near the retreating ice. The pebbles would be left behind as a pavement, while sand and then loess would be deposited farther from the ice where the winds were weaker and where vegetation was beginning to take root. Such a decrease in wind velocity may explain the occasional vertical gradation from gravel through sand to coarse loess and then to normal fine loess. As the ice sheet retreated, the wind in any given place would gradually become less violent. As the ice continued to retreat, the area where loess was deposited would follow at a distance, and thus each part of the gravel pavement would in turn be covered with loess.

The hypothesis that loess is deposited while the ice is retreating is in accord with many other lines of evidence. For example, it accords with the boreal character of the mammal remains as described above and of the depauperated snail fauna found in the zone nearest the ancient ice sheets. Again, the advance of vegetation into the barren zone along the front of the ice would be delayed by the strong out-blowing winds. The common pioneer plants depend largely on the wind for the distribution of their seeds, but the glacial winds would carry them away from the ice rather than toward it. The glacial winds discourage the advance of vegetation in another way, for they are drying winds, as are almost all winds blowing from a colder to a warmer region. Such winds, however, would interfere less with the northward spread of grasses propagated by root shoots and by abundant seeds than it would interfere with the spread of trees. The fact that remains of trees sometimes occur at the bottom of the loess probably means that the deposition of loess extended into the forests which almost certainly persisted not far from the ice at its maximum advance. This seems more likely than that a period of severe aridity before the coming of the glacier killed the trees and made a widespread steppe or desert. Penck's chief argument in favor of the formation of loess before the advance of the ice rather than after appears to be that since loess is lacking upon the youngest drift sheet in Europe it must have been formed before rather than after the last or Würm advance of

the ice. This argument is not convincing for two special reasons: First, on the corresponding (Wisconsin) drift sheet in America loess is present—in small quantities to be sure, but unmistakably present. Second, there is no reason to assume that conditions were identical at each advance and retreat of the ice. Indeed, the fact that in Europe, as in the United States, nearly all the loess was formed at one time, and only a little is associated with the other ice advances, points clearly against Penck's fundamental assumption that the accumulation of loess was due to the approach of a cold climate. The relative abundance of loess associated with the Iowan ice sheet would be explained by the present hypothesis if ice retreated more rapidly for a time than did any of the later ice sheets.

Thus the hypothesis that the loess accumulated chiefly during the retreat of the ice sheets appears to have enough support to merit consideration by students of loess.

MEMORIAL EDITORIAL

ROLLIN D. SALISBURY

August 17, 1858—August 15, 1922

It is with deep sorrow that the *Journal of Geology* records the death of its active managing editor, Dean Rollin D. Salisbury. After a severe illness of two and a half months, he passed away on the evening of August 15, within two days of his sixty-fourth birthday. For the past four years he had been the responsible editor of the *Journal*, while from its founding in January, 1893, he participated actively in the general responsibilities of its editorial management and had special charge of contributions relating to the physiographic aspects of geology. This special service in the dissemination of the literature of the science of the earth thus ran through a period of almost thirty years. The more than 1,300 standard articles, 2,500 abstracts and reviews, 150 editorials and shorter notices, embracing more than 24,000 pages of printed matter, which received all phases of editorial care from the reading of manuscript to the approval of the final proof, attest at once the importance and the burden of this work. Professor Salisbury himself prepared 82 contributions.

The scientific investigations of Dr. Salisbury will be reviewed in a later article more fully than is possible here. His field work was begun under the auspices of the United States Geological Survey as early as 1881 and continued until 1910. It embraced extensive studies on the glacial and other Pleistocene formations of the northern states and the lower Mississippi Valley. In connection with this, he made a report on Crowley's Ridge to the Geological Survey of Arkansas. From 1891 to 1910 he was geologist in charge of the Pleistocene Division of the Geological Survey of New Jersey, where his work on the older drift and on fluvial deposits formed near the neutral zone between marine and upland horizons was notable for its keen insight and acute discrimination. He made important contributions to the Geological Survey of Illinois and

in 1919 was appointed to the Board of Commissioners in charge of the Survey. Besides these official services he made independent investigations in several lines. He was geologist of the Peary Relief Expedition to Northern Greenland in 1895, in connection with which he studied existing glaciers under the unparalleled advantages presented in very high latitudes.

Dr. Salisbury was a very lucid writer. The reports of his researches and the texts of the several works he prepared for the general reader and for students put into the easy possession of others what he saw so clearly himself. The printed results of his studies in field and office will long stand as a lasting memorial to Professor Salisbury's industry and clarity of vision.

Large and important as were these contributions, Dr. Salisbury's greatest service to science lay in his singular success in stimulating and training young talent not only for the teaching of science but for research. This distinguished service began at Beloit College, 1883–91, was continued at the University of Wisconsin, 1891–92, and was transferred to the University of Chicago at its opening, where he took part in founding the Department of Geology thirty years ago. For nearly twenty years he was active executive of the Department and for the last four years bore its full responsibilities. In connection with this geological service he developed the Department of Geography and served as its head from 1913 to 1918, when he was made head of the Department of Geology, and the Department of Geography was transferred to one who, first as a student under him, and then as a colleague, had grown to marked efficiency. From 1899 onward Dr. Salisbury was dean of the Ogden (Graduate) School of Science of the University of Chicago. In these varied relations he came into touch with thousands of young minds and gave them effective impulses toward sound scholarship and the higher life. The ultimate effects of this work are beyond estimation. Through the growing efficiency and the rising power of the young talent thus inspired by his leadership, Dean Salisbury's greatest service to science and to humanity has only fairly begun.

T. C. C.

Petrological Abstracts and Reviews

ALBERT JOHANNSEN

Harker, Alfred. *Petrology for Students.* Cambridge, 1919, 5th ed. Pp. 300, figs. 100.

A comparison of the fifth with the fourth edition of Harker's book shows the chief change to be that practically all of the American examples have been "improved out." With the exception of one chapter where nephelite- and leucite-syenites are now separated from the syenites, the two editions could be used in the same class, for though the pagination is different, the different paragraphs can be easily located. The change of the chapter heading "Diabase" to "Dolerite" will not be considered an improvement in this country. Both terms are bad, in that each has two meanings; the former being used for ophitic dike-rocks of the composition of gabbros as well as for Paleozoic basalts, the latter, originally for coarse-grained basalts, now according to British usage for the rocks we call diabase. Harker still clings to the classification of diorite as a hornblende-bearing rock (p. 63) while gabbros are defined as "characterized by pyroxenes in place of hornblende" although he recognizes the modern tendency in classifications when he says: "The distinction between the hornblende- and augite-bearing types is rather an artificial one. It was established before the strong tendency of augite to pass over into hornblende was thoroughly appreciated." Also, "The family as so defined cannot be regarded as a natural one." The feldspar of diorite is given as "andesine or labradorite or exceptionally a more basic variety," while in gabbros it is given as "labradorite, with exceptionally one more acid and occasionally orthoclase."

Hirschwald, J. *Leitsätze für die praktische Beurteilung, zweckmässige Auswahl und Bearbeitung natürlicher Bausteine.* Berlin, 1915. Pp. 36, figs. 18.

This book was primarily written for stone-workers and aims at giving the most important points needed in the selection and judging of building-stone. There is a short classification of rocks giving the desirable and undesirable characteristics of each, a chapter on the examination of stone quarries with examples of written forms for describing quarries, and chapters on the essentials of stone-testing, advantageous modes of working and using certain rocks with reference to schistosity, cleavage, etc., various uses of different kinds of stone, etc.

HOLMES, ARTHUR. *The Nomenclature of Petrology.* London, 1920. Pp. 284.

This little book is intended as an English substitute for Loewinson-Lessing's *Lexique Pétrographique,* which is now about twenty years old. It is a very convenient and useful volume, giving in brief form, definitions of most of the common terms used in petrology. The only fault that might be found with it is that it is too brief, and that the references are, in many cases, not to the work in which the term was originally given, but usually to later British authors. In other cases references are hard to find; for example, the reference for the source of umptekite is under "chibinite," and maenaite under "grorudite," but this can hardly be called satisfactory, especially since no hint is given as to the terms under which they may be found. Other references, such as "Syenodiorite, Evans, 1916," etc., are too incomplete to be traced. On the whole, however, the book is very good, and it is likely to prove useful to students by giving them the means for quickly finding unfamiliar terms.

HOLMES, ARTHUR. *Petrographic Methods and Calculations.* London, 1921. Pp. 515, figs. 83, pls. 4.

Quite different from previously published books on petrographic methods is this one by Holmes, in that very little space is devoted to optical methods. The author says in his preface, "I have tried to produce a more evenly balanced treatise which should penetrate the petrological domain, and not merely skirt its border land." Chapter i deals with Petrology, its scope, aims, and application, chapter ii with specific gravity, chapter iii (40 pp.), separation of minerals by heavy liquids, magnet, etc., chapter iv (52 pp.), optical examination of minerals, including not only optical properties but tables for the determination of minerals, chapter v (71 pp.), the examination of detrital sediments, chapter vi (19 pp.), the preparation of thin sections, chapter vii (45 pp.), microchemical and staining methods, chapter viii (38 pp.), the examination of thin sections, including a discussion of the Rosiwal and similar methods, genesis of minerals, saturated and unsaturated minerals, etc. Incidentally it is stated that "Johannsen has suggested the use of a planimeter for measuring areas of particular minerals on a drawing of a thin section made with the aid of a camera lucida. The procedure is more complicated and tedious than the ordinary linear method now in general use." But in the method mentioned no camera lucida drawing is made and the time required is less than a fourth of that of the Rosiwal. Chapter ix deals with rock textures, chapter x with chemical analyses and their interpretation and includes a discussion of the C.I.P.W. system, and chapter xi with graphical representation of chemical analyses. The book thus brings together much of the miscellaneous data so often needed by the petrographer. It will therefore be examined with interest and profit by all advanced workers in the science.

HOMMEL, W. "*Systematische Petrographie auf genetischer Grundlage*," Vol. I, *Das System*. Gebrüder Borntraeger, Berlin, 1919. Pp. xii+174, figs. 5, pls. 5.

Hommel proposes a double-barreled system of classification, in that he represents a rock by a formula composed of two parts. The first, which he calls his "Molekularformel," is derived directly from the chemical analysis and represents the molecular proportions of the various oxides. The second, or "Konstitutions formel," represents the percentages of certain minerals calculated from the chemical analysis. The percentages of the computed minerals, however, resemble those of the normative minerals of the C.I.P.W. system. since they generally do not represent the amounts actually present in the rock. As in the C.I.P.W. system, the feldspars are calculated from the amounts of K_2O, Na_2O, and CaO present in the analysis. Orthoclase is considered pure K_2O, Al_2O_3, $6SiO_2$, and all the soda is calculated as part of the plagioclase. As a matter of fact, a considerable amount of the soda may occur in the orthoclase or microcline as lamellar intergrowth, either visible or invisible. Where all is calculated in the plagioclase, the resulting mineral is too near the soda end. Potash in muscovite is disregarded, and the only lime or alumina used for the dark minerals is that which occurs in excess of the requirement of the theoretical feldspars.

So far as the first part of the formula is concerned, no objection can be made to it, since it is confessedly chemical. It has the advantage of simplicity over the C.I.P.W. system, and can be shown in a diagram. Whether it is better than Osann's system is a question. Certainly Osann's latest modification (*Der chemische Faktor in einer natürlichen Klassifikation der Eruptivgesteine*, Heidelberg, 1919. Review to follow in this *Journal*) offers a rapid means for finding rocks of similar composition. Since only Part I of Hommel's book is printed, however, it is possible that similar groups of rocks may appear later.

Hommel's system can best be illustrated by an example. The kern granite of the Brocken in molecules, reduced to 100, gives SiO_2 80.2, TiO_2 —, Al_2O_3 8.6, Fe_2O_3 0.5, FeO 1.5, MgO 0.4, CaO 1.4, Na_2O 3.3, K_2O 4.1. Hommel's formula for this rock is:

$$80.2\ \overset{3\cdot3}{\underset{1\cdot2}{\Sigma}}\ 4.1\ \dot{F}\ \overset{\cdot\cdot\ \cdot\cdot}{\underset{2}{\dot{e}}}\ \dot{m}c\ 2.6 = +31\ P\ \left[\dot{O}_{33}\dot{O}l^{\circ}_{31}\right]\dot{\beta}\ 5.$$

The first part is the molecular formula and is obtained as follows: The figures 80.2 represent the amount of the silica molecules (plus TiO_2 and P_2O_5) as computed above. The large figures immediately after the sign Σ represent the K_2O molecules; the Na_2O mol. and the CaO mol. in feldspar being represented by the figures above and below the sign. The CaO figures necessarily cannot be greater than the amount of Al_2O_3 remaining after enough has been used to satisfy the soda and potash. Excess CaO is added to the mafic minerals as *c*. The mafic constituents are represented by *e* for Fe_2O_3, *f* for FeO+MnO, *m* for

MgO, and *c* for the remaining CaO. If all of the CaO was used for feldspar, the excess of Al_2O_3 is represented by *t* among the mafic constituents. If there is insufficient Al_2O_3 to satisfy the alkalies, the remaining Na_2O is indicated by *n* and it also is placed among the ferromagnesian constituents. In the above example, $K_2O+Na_2O=4.1+3.3=7.4$, corresponding to 7.4 Al_2O_3 leaving 1.2 Al_2O_3 to unite with CaO for the anorthite radical. The remaining 0.2 CaO is represented by *c* among the mafic constituents. The ferromagnesian constituents are given in the order of decreasing abundance, and their sum is represented by the figure following (here 2.6). The relative abundance is indicated in the symbol, thus

fm indicates an FeO/MgO ratio below 5 FeO/4 MgO.

$\dot{f}=1\frac{1}{2}$ f, therefore $\dot{f}m$ shows a ratio between 4FeO:3MgO and 3FeO: 2MgO.

$\ddot{f}=2$ f, or $\ddot{f}m$ indicates the ratio of 2/1.

F=3f, and Fm=3 FeO to 1 MgO.

$\dot{F}$=4f, and $\dot{F}m$=4/1.

$\ddot{F}$=5f, and $\ddot{F}m$=5/1.

F_2=6f,

$\ddot{F}_2$=8f,

$\dot{F}_2$=10f,

F_4=12f, etc., etc.

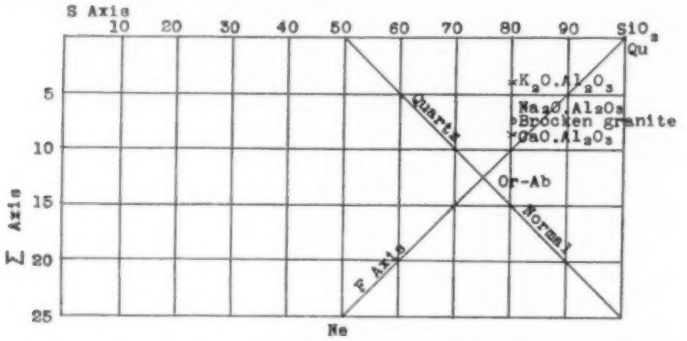
Since the remaining constituents in the order of decreasing abundance in the example given are FeO=1.5, Fe_2O_3=0.5, MgO=0.4, and CaO=0.2 (the ratios being therefore as 7 : 2.5 : 2 : 1 approximately), they are represented by $\dot{F}_2 : \ddot{e} : \ddot{m} : c$. (These symbols are complicated. Why not use the ratio directly as subscripts; thus here $F_{1.5} . e_{0.5} . m_{0.4} . c_{0.2}$, or even the simplified similar ratios $F_7 . e_{2.5} . m_2 . c$).

The rock may be plotted on rectangular co-ordinates as shown by the figure. The horizontal line (*S* axis) represents the silica content. The vertical line through 50 per cent is the Σ axis and is the measure of the feldspar content. It is drawn at double the scale of the *S* axis because for each molecule of alkali or lime, a molecule of Al_2O_3 is also automatically included. Further, there are two diagonal lines at 45° through the 50 per cent and 100 per cent points on the *S* line; the former is called the quartz normal, the latter the *F* axis.

The Brocken granite is thus plotted by measuring from the 80.2 point on the *S* axis downward 4.1 for K_2O. This *K* point is indicated by an *x*. A further distance of 3.3 for Na_2O is laid off on the same line and the point is marked by a circle. This is called the Locus of the rock (*Ort des Gesteins*). Finally 1.2 is

plotted on the extension of the line for CaO, and this is also marked by an x. This is the Σ point. The horizontal distance of the Σ point from the F axis (in units as measured on S) gives the amount of the ferromagnesian constituents. The amount of free (theoretical) quartz is given by the horizontal distance of the Locus of the rock from the "Quartz normal." (As measured on the S scale, the reading is to be multiplied by 2.) In the case of the Brocken granite this distance is 15.4, therefore the theoretical amount of free quartz is 30.8.

Since the quartz normal and the F axis are both at 45°, the readings may be made along the downward extension of the line passing through the locus of the rock, instead of along the horizontal.



The second part of the formula, the "Konstitutionsformel," represents theoretical minerals. The method for computing the free quartz follows from the diagram. Twice the sum of the alkalies is subtracted from the silica value less fifty (the diagonal line starting at the 50 point), and the result is multiplied by two.

Free quartz $= 2[(SiO_2 - 50) - 2(K_2O + Na_2O)]$, where SiO_2, K_2O, etc., are molecular values. The Brocken granite therefore gives $2[(80.2 - 50) - 2(4.1 + 3.3)] = +30.8$ or approximately $+31$. The plus sign gives the position of the rock above the quartz normal in the diagram, and shows free quartz. Below the line is shown by a minus sign. This indicates nephelite, olivine, etc. The letter P (plutonic) indicates the texture. O stands for orthoclase. Its value is obtained by multiplying the K_2O mol. by 8, since the formula is $K_2O.Al_2O_3.6SiO_2$. ($K_2O = 4.1$, $O = 8 \times 4.1 = 32.8$ or ca.33). The plagioclase indicated by the molecular formula is 3.3 Na_2O, 1.2 CaO, or basic oligoclase, Ab_6An_1. The molecular value of the albite is eight times the Na_2O, but the anorthite, with the formula $CaO.Al_2O_3.2SiO_2$ is only four times the CaO. ($3.3 \times 8 + 1.2 \times 4 = 31.2$). The symbol for basic oligoclase is Ol°. Beta indicates biotite, and 5 per cent represents the remainder left for this mineral. It amounts, of course, from the formula $RO.SiO_2$ to twice the F value.

With insufficient Al_2O_3, the symbol Δ is used in the formula instead of Σ, and the aegirite molecule takes the place of the anorthite. Thus Δ 4 means

$4(K_2O.Al_2O_3)$. $6(Na_2O.Al_2O_3)$. $2(Na_2O.\ Fe_2O_3)$. These rocks may contain free quartz (or nephelite). Where there is quartz it is to be noted that only four molecules of SiO_2 are required to one of Na_2O, consequently there will be more quartz than in the case where all the soda goes into feldspar. The formula for the quartz, in this case, consequently, reads $2[(SiO_2 \text{mol.} - 50) - \{2(K_2O \text{ mol.} + Na_2O \text{ mol.}) + \text{aeg. mol}\}]$.

With insufficient silica, so that a negative result is obtained by the quartz formula, it is evident that olivine or nephelite (or leucite) is present. The formula here is divided instead of multiplied by 2, and we have nephelite $= \frac{SiO_2 - 50 - [2(K_2O + Na_2O) + \text{aeg. mol.}]}{2}$ (the alkali molecules are those in feldspar and feldspathoid only).

Examples of the nephelite rocks and rocks with insufficient alumina would make this abstract too long.

The third section of the book consists of a natural classification of rocks on genetic principles. A detailed description is impossible here and the reader is referred to the original work which is full of suggestions. Briefly, rocks are divided into five groups: (1) the orthogene class of rocks includes those formed by slow cooling in the interior of the earth; (2) the paragene class originated in a relatively rapid cooling of the magma during the period of crystallization of olivine, consequently that mineral could not settle out but is represented by its recrystallizations as diopside, etc.; (3) the hypogene class includes extrusive rocks formed under conditions of rapid cooling, relief from pressure, and movement; (4) peratogene rocks are those altered by metamorphism and include the crystalline schists; (5) diagene rocks include the sediments. The first four groups are subdivided into ten zones each, each zone representing a distinct temperature-interval through which the magma passed on cooling, and marked by the separation of typical and chemically well-defined minerals. There are thus the zones of (1) chromite, (2) olivine, (3) enstatite, (4) diopside, (5a) labradorite, (5b) nephelite, (6) labradorite-andesine, (7) andesine, (8a) andesine-oligoclase, (8b) oligoclase, (9) orthoclase, (10) quartz.

The book is one which will repay very careful study in every part. While one might wish that the "Konstitutionsformel" represented actual rather than theoretical minerals, one can easily understand how the former might make difficulties in certain cases. Undoubtedly this book is one of the most important works on petrography that has appeared in recent years.

IDDINGS, J. P., and MORLEY, E. W. "A Contribution to the Petrography of the South Sea Islands," *Proc. Nat. Acad. Sci.*, IV (1918), 110–17.

This is a preliminary statement of the geological structure and character of seven islands of the South Seas, including Tahiti, Moorea, and the Society Group. Thirty new chemical analyses are here published for the first time.

The rocks of Tahiti are almost wholly olivine basalts, some with nephelite or analcite. Trachytic and phonolitic lavas occur on five of the seven islands. A nephelite-latite, consisting of alkalic feldspar and andesine with some nephelite and sodalite and abundant hornblende, much titanite, and few augites and micas is given the new name of *tautirite*, from the valley, Tautira, Taiarapu, in which it occurs. The mode is not given but the norm contains Or 31.1, Ab 28.3, An 13.3, and Ne 10.8.

JEHU, T. J., and CAMPBELL, ROBERT. "The Highland Border Rocks of the Aberfoyle District," *Trans. Roy. Soc. Edinburgh*, LII (1917), 175–212, figs. 10, pls. 6.

A series of grits, shales, limestones, cherty shales, graphitic shales, and various igneous rocks, in places highly altered, extending from Stonehaven to Arran, is grouped under the term "The Highland Border Rocks." They are here arranged in two divisions. The sediments of the Lower Series are either Upper Cambrian or transitional between Cambrian and Ordovician, and are thought to have been deposited in clear water near the verge of sedimentation. The lavas indicate submarine eruptions. The Upper Series, which belong higher in the Ordovician, include limestones, hornblende- and chlorite-schists, and igneous rocks.

JOHANNSEN, ALBERT. *Essentials for the Microscopical Determination of Rock-forming Minerals and Rocks in Thin Sections.* Chicago, 1922. Quarto, pp. vi + 54, figs. 24, pls. 6, and a folding table.

This laboratory manual contains practically all of the data originally published in the writer's *Determination of Rock-forming Minerals*, and in addition gives modes of occurrence and many more points of separation between similar minerals. Only a few very rare species, such as johnstrupite, mosandrite, laavenite, etc., have been omitted, but by uniting the tables which contained minerals having birefringences greater or less than quartz, and refractive indices greater or less than Canada balsam, much repetition has been avoided, and the number of pages has been materially reduced. Orthorhombic minerals have been united with the other biaxial minerals, since sections which cut all of the crystallographic axes in this system show inclined extinction, but the extinction angles are given in the descriptions. The separation lines between the various plagioclase feldspars have been changed from those given in the former book to 5, 27½, 50, 72½, and 95 per cent anorthite. Albite and anorthite have been limited to a variation of only 5 per cent since these names are also applied to the pure end members, and compound names, such as oligoclase-albite, labradorite-bytownite, etc., have been omitted. The section on the determination of the feldspars has been but little reduced, but that on optical

methods has been condensed as much as possible, since this data is given elsewhere. The alphabetical list of minerals has been much extended, and is now placed at the back of the book in such a position that it may be consulted without turning pages. Finally, a short section on the classification of igneous rocks according to the author's system has been added. As given here, this classification is essentially the same as that published in the *Journal of Geology* several years ago, except that the whole of the monzonitic series, with the exception of monzonite and quartz-monzonite, has been omitted.

KAISER, ERICH. "Der Eläolithsyenitlakkolith der Serra de Monchique im südlichen Portugal," *Neues Jahrb.*, B. B., XXXIX (1914), 225–67, pls. 2, profiles 2, map 1, figs. 6.

Discusses the structure of the Serra de Monchique in southern Portugal, with special reference to the nephelite-syenite central mass. He considers this a laccolith that was intruded during the period of folding. The main foyaitic mass with border pulaskites, and various dike-rocks are briefly described.

KAISER, ERICH. "Über ein Demonstrationsmikroskop für den mineralogischen und petrographischen Unterricht," *Zeitschr. f. Kryst.*, LIII (1914), 397–403.

Describes a microscope for demonstration purposes. It has a large, rotatable stage with ten openings, so that that number of thin sections can be placed on it at one time, and the specimens observed one after the other. A glass plate prevents the disturbance of the sections by students. Since the preparations cannot be turned there is provided a means for rotating the tube of the microscope.

KAISER, ERICH. "Studien während des Krieges in Südwestafrika," *Zeitschr. d. deutsch. geol. Gesell.*, LXXII (1920), 50–76.

The three studies included in these papers are: (1) Assimilationsercsheinungen an den Elaeolithsyeniten des Granitberg in südlichen Namib," (2) "Zur Kenntnis der Hohlformen, Eindeckungen, Ausfüllungen und Aufschüttungen der Trockengebiete," and (3) "Kalkkrusten." In the first paper the nephelite-syenite stock of Granitberg, in southern Namib, is described. Besides the normal rock there are certain other types which cannot be explained by normal differentiation. The contact of the main mass is irregular and blurred, owing to the penetration of the country rock by numerous veins and apophyses of the igneous rock, thus giving the impression of an irregular breccia penetrated by the nephelite-syenite. But it is not a breccia in the ordinary sense since the fracturing was caused by the intrusion itself. Both intrusive and intruded

rock are altered, the character of the resultant depending upon the nature of the country rock. Against sandstone and arkoses there is a decrease in the feldspathoids and a transition to syenite and even to quartz-bearing and nephelite-free alkali granites. Where the igneous rock is in contact with the dolomitic Cambrian rocks there is an increase in the amount of nephelite and the grain is coarse, in some cases giving nephelite-syenite-pegmatite phases with nephelites several centimeters in size. Such changes in the character of the rock cannot be explained by differentiation alone. Kaiser thinks that assimilation of the country rock is clearly indicated, although he supposes that there was also subsequent differentiation. He warns, however, against using such local occurrences either for or against the assimilation theory of magmas in general. The mechanics of the intrusion, he thinks, agree with Daly's theory of magmatic stoping. He believes the magma reached its present position not by intrusion between strata, but by forming a place for itself.

KAISER, ERICH. "Bericht über geologische Studien während des Krieges in Südwestafrika," *Abhandl. d. Giessener Hochschulgesell.*, II (1920). Pp. 57, pls. 6, figs. 4

A general geological description of Namib, an interesting petrographic description of which is given in greater detail in the preceding paper. The scope of the work is indicated in the chapter headings, some of which are crystalline schists, Cambrian, eruptive rocks, Tertiary, alteration of the Tertiary land surface, underground water, mineral occurrences, etc.

KATŌ, TAKEO. "Microscopic Secondary Sulphide Enrichment in the 'Kuromono' Ore from the Kosaka Mine, in the Province of Rikuchü, Japan, *Jour. Geol. Soc. Tokyo*, XXV (1918), 1–7, pls. 1.

KATŌ, TAKEO. "A Contribution to the Knowledge of the Mesozoic Igneous Rocks Developed Around the Tsushima Basin, Japan, *Jour. Geol. Soc. Tokyo*, XXVII (1920), 1–22, 23–38, pls. 4, figs. 2.

A porphyrite complex with associated tuff beds, late Jurassic in age, was invaded by a series of igneous rocks in the following order: (1) effusive quartz-porphyry; (2) intrusive quartz-masanite, masano-tonalite, etc., with melanocratic marginal facies; (3) tsingtauites and masano-tsingtauites; (4) dikes of masano-hornblendite; (5) aplitic and pegmatitic rocks. The rocks of (1) and (2) were probably derived from the same magma basin; (2), (3), (4), and (5) are clearly related. Sporadic corroded quartz crystals in some portions of the

porphyrite as well as those in many lamprophyres are thought to have sunk from the overlying acid magma layers, in which they were beginning to form, into the basic lower layers from which the basic rocks were derived.

KATŌ, TAKEO. "A Contribution to the Knowledge of the Cassiterite Veins of Pneumato-Hydatogenetic or Hydrothermal Origin, *Jour. Col. Sci. Imp. Univ. Tokyo*, XLIII (1920), Art. 5. Pp. 60, map 1, pls. 6, figs. 11.

Largely economic, although a considerable number of pages are devoted to igneous rocks. Among these are diorite, gabbroid-diorite, diorite-mylonite, and a rock to which the new name "akenobeite" is given. Dike-rocks are hornblende-hypersthene-andesite, garnetiferous-felsite-porphyry, felsite, porphyrites, and diabase, and there is extrusive rhyolite. The rocks are described in some detail but neither chemical nor modal analyses are given. The akenobeite is a quartz-monzonite-pegmatite or -aplite, according to Kato. It consists of tabular crystals of feldspar in haphazard orientation with the interstices filled with an aggregate of quartz. The feldspar is orthoclase and oligoclase, the latter always in excess. How much in excess is not stated, so it is a question whether the rock might not be called a granodiorite-aplite. Biotite is very subordinate and occurs in minute flakes in the feldspars or attached to its borders. In the system of the reviewer it belongs to Class 1, Order 2, Family 7 (new form), and probably in 7″. The amount of quartz is not stated, but from the two photographs given it appears to amount to 15 or 20 per cent.

KLEMM, G. "Die Granitporphyre und Alsbachite des Odenwaldes," *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, IV Folge, Hf. 35, 1914. Pp. 10–50, pls. 2, fig. 1.

In the crystalline schists of the Odenwald there are various dikes of anorthoclase-granite-porphyry and of alsbachite. Of the former rock there are twelve chemical analyses, eight of them apparently new, and of the latter, three, of which two are new. Five new analyses of dike granites are also given. All the analyses are re-computed into Osann's system.

KLEMM, G. "Bemerkungen über die im Gabbro des Frankensteins gangartig aufsetzenden Gesteine und über seine Einschlüsse von Korundfels," *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, IV Folge, Hf. 35, 1914, 5–9.

Describes certain corundum-bearing rocks occurring in the Frankenstein gabbro. The author disagrees with Kalkowsky, who regards them as diff-

erentiation products of the gabbro magma, but considers them metamorphosed inclusions of sedimentary rocks which were resorbed by the gabbro and later recrystallized.

KLEMM, G. "Über die angebliche Umwandlung von Andalusit in Disthen in den Hornfelsen des Schürrkopfes bei Gaggenau in Baden," *Zeitschr. d. Deutsch. Geol. Gesell.*, LXVIII (1916), 86–92.

Eisele regarded the disthene in the hornfels from Schürrkopf in Baden as due to alteration of andalusite by orogenic pressures which were post-contact-metamorphism; Klemm regards the two minerals as contemporaneous products.

KLEMM, G. "Zur Errinerung an Richard Lepsius," *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, V Folge Hf. 1, 1915, 5–22. With portrait and bibliography.

KLEMM, G. "Die korundführenden Hornfelse und die Schmirgelgesteine von Laudenau und Klein-Gumpen bei Reichelsheim im Odenwald und ihre Nebengesteine," *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, V Folge, Hf. 1, 1915, 23–41, pl. 1.

This is a more detailed description of the corundum-bearing rocks of the Odenwald, mentioned in the third preceding abstract. Ten new analyses are given.

KLEMM, G. "Über den 'Variolit von Asbach,'" *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, V Folge, Hf. 2, 1916 (1917), pl. 1.

The "variolite" from Asbach, called diabase by Chelius, is here determined as malchite. The varioles, representing fillings of vesicles, vary in size from hazel-nuts to walnuts, occasionally to the size of eggs. They consist of quartz feldspar, iron ore, and epidote.

KLEMM, G. *Blatt Neunkirchen.* Erläuteru. z. Geol. Karte Hessen. 2d ed. Darmstadt, 1918. Pp. 81, pl. 1.

In this general geological report on the quadrangle lying between lat. 49°48′ and 49°32′, in Hessen, there are short descriptions of many igneous rocks, and analyses of 4 hornfelses, 2 amphibolites, 9 gabbros, 3 hypersthene-gabbros, 3 serpentines, 4 diorites, 14 granites, 5 granite-porphyries, 2 granophyres, 9 malchites, and 6 odinites.

KLEMM, G. "Über die Enstehung der 'Felsenmeere' des Felsberges und anderer Orte im Odenwalde," *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, V Folge, Hf. 3, 1917 (1918), 3–11, pls. 2.

Considers these particular rock-streams as due to removal of interstitial weathered material. The blocks lie practically in the positions where they were originally formed.

KLEMM, G. "Der Granatfels von Gadernheim im Odenwalde und sine Nebengesteine," *Notizbl. d. Vereins f. Erdk.*, etc., z. Darmstadt, V Folge, Hf. 4, 1919, 3–32.

The flaser granite of Gadernheim shows an original contact at the south and east against metamorphosed sediments. This metamorphism was produced by gabbro which altered the sediments to garnetfels, cordierite-hornfels, biotite-hornfels, amphibolite, graphite-schist, and graphite-quartzite. The gabbro itself was altered by endogene contact action to hornblende-gabbro with a dioritic selvage.

KOLDERUP, CARL FRED. "Egersund," *Norges Geol. Undersök*, No. 71, 1914. Pp. 60, pls. 4, map 1.

A geologic report on a quadrangle in the southwestern part of Norway, about 60 km. SSE. of Stavanger. The principal part of the area is composed of labradoritites and pyroxene-poor norites. The composition of one of the latter is given (p. 18) as labradorite 92 per cent, pyroxene 7 per cent. and ilmenite 1 per cent. There is a smaller area of mangerites and norite-mangerites. Among the dike-rocks are mangerite, birkremite, quartz, ilmenite, granite-pegmatite, and diabase.

KOLDERUP, CARL FRED. "Fjeldbygningen i strøket mellem sørfjordem og Sammangerfjorden i Bergensfeltet," *Bergens Museums Aarbok*, 1914–15, No. 8. Pp. 257, figs. 91, colored pls. 2, maps 3.

The district of the Bergen arches is characterized by a peculiar arrangement of the various formations in curves. The rocks are dynamo-metamorphosed and are in part sedimentary and in part igneous. Phyllites are the most common sediments, and consist of quartz and muscovite with various accessories. In the phyllite zone occur serpentines, soapstones, green-schists, saussurite-diabases, saussurite-gabbros, labradoritite, norite, mangerite, and birkremite. The serpentines are considered metamorphosed igneous rocks, probably peridotites or pikrites. The green-schists were probably originally basic volcanic

rocks and tuffs. In the western part of the area are Middle Silurian limestones, metamorphosed to marble. Younger than the marble for it contains fragments of this rock, is the polymict conglomerate. It is probably a volcanic conglomerate whose cement originally was a tuff. The "gray granite" of Reuss is considered a pressed granite.

The structure of the area indicates that the metamorphism must have taken place in the upper part of the earth's crust where one-sided pressure, low temperature, and a considerable saturation with water were factors. The rocks of the inner arch are more strongly compressed than those of the outer, but the materials are of approximately the same kind.

KOTŌ, BUNDJIRO. "The Great Eruption of Sakura-jima in 1914," *Jour. Col. Sci., Imp. Univ. Tokyo*, XXXVIII (1916). Pp. 237, pls. 23, map 1, figs. 46.

Sixty-eight pages of this elaborate report are devoted to petrography. The descriptions are accompanied by 61 photomicrographs on 8 photogravure plates, which are beautifully clear and of considerable help. The author states that "the characterization of the rocks is merely of preliminary qualitative nature." It is to be hoped that quantitative determinations may be published later. The older lavas of the volcano are hypersthene-andesites, and are *dull* black or light brown porous and light in weight; the later lavas are *pitch* black, slaggy, and heavy, and are hypersthene-bearing pyroxene-andesites with sporadic olivine. The lavas of 1914 are also olivine-bearing hypersthene-andesites and are like those of 1779. Among the inclusions in the lava are fragments of earlier segregations, among them a lava composed principally of anorthite (printed anorthosite by mistake on p. 191) with interstitial orthoclase (?). This rock is called microtinite but deserves a new name, since microtinite as described by Lacroix was neither a pure nor nearly pure anorthite rock. No quantitative data as to the relative amounts of the two feldspars are given. The name *ceramicite* is given to porcelain-like ejectamenta which contain cordierite as the characteristic component. The other constituents are basic plagioclase and colorless glass, with subordinate hypersthene. Quartz is said to be totally wanting. With 23 beautiful photogravure plates, one may overlook the muddy half-tones which disfigure the text.

KŌZU, S. (1) "The Dispersion Phenomena and the Influence of Temperature on the Optic Axial Angle of Sanidine from the Eifel;" (2) "The Dispersion Phenomena of Some Monoclinic Feldspars," *Mineralog. Mag.*, XVII (1916), 237–52, 253–73.

Many valuable determinations on the optic axial angles and dispersion in feldspars, which would be more valuable if chemical analyses of the materials used were given.

LACROIX, A. "Les roches basiques non volcaniques de Madagascar," *Comptes Rendus*, CLIX (1914), 417–21.

Anabohitsite is a new name given to a "pyroxenite" with olivine, hypersthene, hornblende, and 30 per cent ilmenite and magnetite. It forms the periphery of the gabbro massif in Anabohitsy. The amount of olivine is not stated. Why not a peridotite? An analysis is given.

LACROIX, A. "Sur un type nouveau de roche granitique alcaline, renfermant une eucolite," *Comptes Rendus*, CLX (1915), 253–57.

A rock composed of much quartz, alcalic feldspar (microperthitic soda-orthoclase or anorthoclase with albite, in other cases albite alone), aegirite, riebeckite, and eucolite, occurring either fine-, medium-, or coarse-grained, is given the name *fasibitikite*. It is compared with rockallite. A chemical but no modal analysis is given.

LACROIX, A. "Sur quelques roches volcaniques mélanocrates des Possessions françaises de l'océan Indien et du Pacifique," *Comptes Rendus*, CLXIII (1916), 177–83.

Describes and gives analyses of two rocks which "are more calcic than feldspathic picrites, generally a little more ferruginous, and a little richer in silica. They are separated from the picrites in that their pyroxene is in excess over olivine. Further the quantity of light-colored constituents is often a little greater." No mineral percentages are given, consequently it is difficult to place it. Possibly a labradorite (?) bearing picrite. To it is given the new name *ankaramite*.

LACROIX, A. "La constitution des roches volcaniques de l'Extreme Nord de Madagascar et de Nosy bé; les ankaratrites de Madagascar en général," *Comptes Rendus*, CLXIII (1916), 253–58.

Melanocratic nephelite-basalts with considerable feldspar and phenocrysts of olivine, titaniferous augite in the form of microlites, ilmenite, often perofskite, and biotite are given the new name *ankaratrite*. The nephelite never forms more than 10 to 15 per cent of the rock and is in many cases accompanied by melilite. With simply a description for a definition, its relationship to other rocks is indeterminable.

A granular rock formed of augite and nephelite with a little olivine, biotite, apatite, and some orthoclase is called *fasinite*. Rosenbusch's *definition* of bekinkinite would cover this rock, but Lacroix says the *rock* from Bekinkiny

generally contains plagioclase, is always richer in hornblende, and has part of the nephelite changed to analcite. The unfortunate usage of giving locality names to new rock types is ever a cause for confusion. Should the original definition be considered the standard, or must a rock possess every accessory of the original rock to be of the same type, that is, should the words of the definition or the rock from a certain locality be the standard? If the latter, then practically every outcrop should have a new name, for slight variations will always be found.

LACROIX, A. "Les syénites à riebeckite d'Alter Pedroso (Portugal), leurs formes mésocrates (lusitanites) et leur transformation en leptynites et en gneiss," *Comptes Rendus*, CLXIII (1916), 279–84.

Under *lusitanite*, after the name of the country where found, there is described a mesocratic riebeckite-aegirite-syenite. Where new names are based upon variations in the mineral percentages, modal percentages should be given.

LACROIX, A. "Les laves à haüyne d'Auvergne et leurs enclaves homoeogènes," *Comptes Rendus*, CLXIV (1917), 581–87.

Ordanchite is applied to certain hauynite-tephrites from la Banne d'Ordanche. Phenocrysts of plagioclase ("oscillent entre le labrador et l'andésine"), blue hauynite, more or less corroded hornblende, and augite are visible to the unaided eye. Microscopically there are seen in addition titaniferous magnetite, titanite, apatite, and rarely olivine. *Tahitite*, after its occurrence on Tahiti, is a lava resembling ordanchite but more alcalic. Lacroix considers it a microlitic form of nephelite-monzonite. It contains phenocrysts of hauynite in a vitreous groundmass of microlites of augite, titaniferous magnetite, hauynite, and perhaps a little orthoclase and leucite. *Mareugite* is a name given to a medium-grained rock from Mareuges, Auvergne, which contains 60 per cent light minerals (bytownite and hauynite). The dark minerals present are not mentioned, but in an associated rock, called type two, they are hornblende, augite, titaniferous magnetite, and a little blue hauynite, and therefore they apparently also occur in the mareugite.

LACROIX, A. "Les laves leucitiques de la Somma," *Comptes Rendus*, CLXV (1917), 481–87.

Vesuvites are the leucite-tephrites from Vesuvius. Four apparently new analyses are given. Nine analyses of "ottajanites" are also given. They contain more plagioclase and less leucite than the vesuvianites, but since no proportions are given the dividing lines cannot be stated. Terms such as more, less, little, and much are of no value for comparison.

LACROIX, A. "Les roches grenues d'un magma leucitique étudiées à l'aide des blocs holocristallins de la Somma," *Comptes Rendus*, CLXV (1917), 205–11.

Ottajanites are leucite-tephrites having the chemical but not the mineralogical composition of sommaites. They are microlitic and contain leucite and plagioclase. *Vesuvites* are the leucite-tephrites of Vesuvius. These are described in more detail in a later publication (see next abstract). *Puglianites* are coarse-grained rocks composed of automorphic augite in a groundmass of leucite and anorthite. Certain varieties contain a little biotite, hornblende, and orthoclase. *Sebastianites* are like the puglianites chemically but are different mineralogically. They are composed of more or less automorphic anorthite, with a little augite, apatite, and biotite. Leucite is absent, all the potash being in the biotite. Chemical analyses but no modal percentages are given.

LACROIX, A. "Les formes grenues du magma leucitique du volcan laziale," *Comptes Rendus*, CLXV (1917), 1029–34.

Braccianite is applied to certain leucitites from the Lake of Bracciano but why given a new name is not clear, except to distinguish them from the Capo di Bove leucitites.

LACROIX, A. "Dacites et dacitoïdes, à propos des laves de la Martinique," *Comptes Rendus*, CLXVIII (1919), 297–302.

According to Lacroix, petrographers classify as dacite only those quartz-bearing andesites which have phenocrysts of quartz; those having quartz in the groundmasses or hidden in glassy groundmasses, and therefore only shown chemically, he says are called andesites. The latter rocks he would call dacitoides. He would extend the term to cover, not only the extrusive equivalents of the quartz-diorites, but also quartz-gabbros, in that he would have oligoclase-, andesine-, and labradorite-dacitoides, to the further confusion of present nomenclature. (H. S. Washington, *Amer. Jour. Sci.*, L [1920], 456, objects to these terms and uses Rosenbusch's term hyalodacite.)

LACROIX, A. "La constitution minéralogique et chimique des laves des volcans du Tibesti," *Comptes Rendus*, CLXIX (1919), 169–75.

In this paper *basanitoïdes* is proposed for basanites in which the nephelite is not crystallized but remains "potential in the glass." Chemically they are basanites.

LAITAKARI, AARNE. "Einige Albitepidotgesteine von Südfinnland," *Bull. Comm. Geol. Finlande*, No. 51, 1918. Pp. 13, figs. 5.

The term *helsinkite* is proposed for a haphazard-textured dike-rock, consisting of albite and epidote, and in some cases quartz (quartz-helsinkite). There is, in some cases, a little microcline, biotite, apatite, and iron ore. The amount of epidote varies from 15 to 35 per cent. In the specimen analyzed there is about 31 per cent epidote and 67 per cent feldspar, of which microcline forms less than 5 per cent (see review of Mäkinen), consequently it belongs, in the reviewer's system, to 2112 (new form). Both albite and epidote are thought to be primary magmatic minerals, the CaO having formed epidote rather than anorthite in plagioclase on account of greater water content and lower temperature of crystallization than the surrounding granite.

LAITAKARI, AARNE. "Über die Petrographie und Mineralogie der Kalksteinlagerstätten von Parainen (Pargas)," *Bull. Comm. Geol. Finlande*, No. 54, 1921. Pp. 113, figs. 40, pls. 3.

The island of Ålö, in South Finland, consists principally of migmatite, a mixture of granite and gneiss. Within this rock are long, narrow lenses of limestone, calcareous gneiss, and amphibolite, which represent remnants of strata which were infolded in the igneous rock. Cutting all these rocks there are granitic and basic dikes. A short introduction of 5 pages, descriptions of rocks 28 pages, descriptions of minerals 57 pages, contact action 7 pages, mineral paragenesis and metamorphism of the limestone 5 pages, and a bibliography of 7 pages comprise the report.

LARSEN, ESPER S. "The Microscopic Determination of the Nonopaque Minerals, *Bull. 679, U.S. Geol. Survey*, Washington, 1921. Pp. 294.

In this very valuable bulletin, Mr. Larsen gives data for determining by their refractive indices all of the transparent minerals recognized by Dana in his *System of Mineralogy* as well as a considerable number not given by him. Thus, if the optical properties are known, there is afforded a rapid means for determining the minerals by immersion in liquid media of known indices. Furthermore, about 125 pages give the results of new measurements of optical constants of about 500 species for which data was not previously available. The bulletin is invaluable and should be in the hands of every petrographer.

LARSEN, ESPER S., and HUNTER, J. F. "Melilite and Other Minerals from Gunnison County, Colorado," *Jour. Washington Acad. Sci.*, IV (1914), 473–79.

While this paper is principally mineralogic, here is first proposed the new name *uncompahgrite*, from the Uncompahgre quadrangle, Colorado, where the

rock was found. It is a coarse-grained rock made up of about two-thirds or more melilite, with considerable pyroxene, magnetite, perofskite, and apatite, while in places biotite, calcite, and other minerals occur. In texture it is commonly coarse, but varies. Cleavage pieces of melilite a foot across and mottled by inclusions of other constituents are not uncommon. The finest grained rock is hypautomorphic-granular with crystals averaging 1 mm. across. In the new system of the reviewer, the rock belongs to 2125.

LARSEN, ESPER S., and MANSFIELD, GEORGE R. "Nepheline Basalt in the Fort Hall Indian Reservation, Idaho," *Jour. Washington Acad. Sci.*, V (1915), 463–68.

The mode of this nephelite-basalt, as given by Mr. Larsen, is nephelite 20, diopside 39, forsterite 26, biotite 8, magnetite 3, ilmenite 1, and apatite 1 per cent. In the reviewer's system it belongs in 3125 (new form).

LEHMANN, E. "Die Ermittlung der Brechungsexponenten der Mineralien im Dünnschliff durch Vergleich mit Canadabalsam und Kollolith," *Centralbl. f. Min.*, etc., (1921), 102–12.

The refractive index of Canada balsam in certain slides was found to be lower than the recently accepted values, being less than 1.5243. A series of experiments with Kollolith showed that the refractive index depended upon the original solvent and upon the temperature of heating. With hard kollolith and a temperature of 150° to 156°, the resulting mount was found to have practically a constant value of 1.5335, but with kollolith dissolved in xylol exposed to air, or under cover-glasses, the values varied from 1.519 to 1.5343, though the first averaged values between 1.5231 to 1.5343 and the latter 1.5257 to 1.5298, depending upon the time of exposure to the air, the higher values being obtained after about six weeks.

LYNES, HUBERT, AND SMITH, W. CAMPBELL. "Preliminary Note on the Rocks of Darfur." *Geol. Mag.*, LVIII (1921), 206–15.

The author describes rocks from the volcano of Dereiba and from various other points between there and El Obeid, Africa. None from this area has previously been described. Troctolite, granite, graphic granite, sandstones, gneisses, and quartz-monzonite occur on the road. The rocks of the volcano are quartz-bearing soda-trachyte, soda-trachyte, quartz-bearing riebeckite-trachyte, andesine-bearing kenyte, and mugearite.

MÄKINEN, EERO. "Översikt av de Prekambriska Bildningarna i Mellersta Österbotten i Finland," *Bull. Comm. Geol. Finlande*, No. 47, 1916. Pp. 152, map 1, figs. 25.

The pre-Bothnian rocks of the district described are represented by two small areas of ortho-gneisses. The Bothnian complex consists of plagioclase-

gneiss, mica-schist, conglomerate-gneiss, quartzite, and limestone, with some leptites. All but the latter are of sedimentary origin. Even the plagioclase-gneiss, which in chemical composition approaches certain igneous rocks, is sedimentary. The rocks have been formed, to a considerable extent, of unweathered volcanic material (volcanic ashes, as well as mechanically disintegrated materials from tuffs and lava beds) partly assorted and deposited in water. Associated with these rocks are certain intrusives and extrusives, mainly plagioclase-porphyrites, uralite-porphyrites, and amphibolites. The post-Bothnian rocks form a comagmatic series, chiefly abyssal but in part hypabyssal in character. The rocks are granite, syenite, granodiorite, quartz-diorite, diorite, gabbro, diabase, hornblendite, and peridotite. In the southwestern part of the area there were apparently two periods of intrusion from a magma differentiated *in situ*. In the parish of Haapavesi to Kivijärvi, there is no evidence of two periods of intrusion but the rocks, from granite to granodiorite and gabbro, grade into each other. The northern and eastern part of the area is an area of migmatites. Here the magma has been differentiated to a certain extent, but the different rocks have not been separated to form large homogeneous masses. The older rocks have undergone fairly complete assimilation by the magma. In the reviewer's modified classification the ortho-gneiss is $227'$ (a granodiorite-gneiss), the plagioclase-porphyrite is 228 (quartz-diorite porphyry or tonalite-porphyry), four granodiorites are all $227'$ (granodiorites in the broad sense, but quartz-monzonites if this group is included in the classification), twelve microcline-quartz-diorites are $227'$ (monzotonalites narrow, or granodiorites in the broad sense), three tonalites are 228 (tonalite), a tonalite-gneiss is $227'$ (monzotonalite-gneiss), three quartz-diorites are 228 (tonalite), a quartz-diorite is 328 (mela-tonalite), a diorite is $227'$ (monzotonalite), two biotite-granites are $227''$ (adamellites in the narrow, or granodiorites in the broad sense), an olivine-gabbro is 2312, and two soda-syenites are $2111'$ (an albite-monzodiorite in the narrow, or albite-syenodiorite in the broad sense. The latter is the rock to which Laitakari compares his albite-epidote rock which he calls helsinkite. Laitakari's rock is given above in the reviews as 2112, from definition, but he says it may in some cases have a little microcline. The present rocks contain enough microcline,one 11 and one 7 per cent, to throw them into the next family.)

REVIEWS

Preliminary Report on the Deposits of Manganese Ore in the Batesville District, Arkansas. By HUGH D. MISER. Bulletin 715-G, United States Geological Survey, Government Printing Office, Washington, D.C., 1920. Pp. 93–124 (32), pls. 3, figs. 4, bibliography, tables, and analyses.

The Batesville manganese district is in the southern part of the Ozark region, in Independence, Sharp, Izard, and Stone counties, in north-central Arkansas. The deposits have been worked intermittently since 1849. They lie in a region of rough topography but of no great relief. In the manganese-bearing areas the following formations are exposed:

Age	Formation
Mississippian	Boone shert
Ordovician	Cason shale
	Fernvale limestone
	Kimmswick limestone
	Plattin limestone
	Joachim limestone
	St. Peter sandstone

The Cherty Fernvale limestone is the principal source of manganese ore. Its weathering leaves cherty nodules and sticky residual clay, varying in color from yellow to red. The overlying thin Cason shale bears phosphate, here as pebbles almost an inch in diameter, there as shell fragments or grains; such phosphate deposits have, however, not been extensively worked. The only fossils in the formation are flattened "buttons" of supposedly algal origin, composed of calcium or manganese carbonates; the "buttons" may occur in great quantity in the residual clay, as at the Cason mine.

Structurally the beds are almost flat-lying; a general doming of the region has given them a gentle dip southward, upon which are superimposed several minor flexures. There are seven small normal faults, with a throw not exceeding 400 feet. An uncomformity separates Mississippian and Ordovician beds and four others occur in the Ordovician sequence.

The manganese minerals are psilomelane, hausmannite, braunite, manganite, pyrolusite; and wad. Psilomelane is most abundant. Iron oxides (limonite and hematite), and ferruginous manganese ores (hematite and limonite with psilomelane), barite, quartz, calcite, arsenopyrite, and sulphides of the heavy metals are also associated with the ores. The workable manganese and ferruginous manganese deposits occur under the following conditions: (1) replacement deposits in the Cason shale and its residual clay; (2) replacement deposits in the Fernvale limestone; (3) residual deposits from the Fernvale limestone; (4) replacement deposits in clays; (5) transported stream-gravel deposits. Of these, (3) is most important as a source of manganese ores, and (1) has furnished more ferruginous manganese. The replacement deposits in the Cason shale and its residuum occur in irregular masses, "buttons," or horizontal seams and beds; "buttons" of red iron oxide are also found under similar conditions. The occurrence of manganese-bearing calcite suggests that all the manganese oxides were derived from the carbonate. A similar origin for the manganese replacements in the Fernvale limestone is well demonstrated by deep cuttings in the district: here cores of carbonate are found surrounded by envelopes of oxides of manganese and ferruginous manganese.

The largest yield of manganese ore, the largest reserves, and a considerable part of the low-grade ore output comes from the residual deposits of the Fernvale or lower limestones, into the deeper portions of which the nodules were settled by gravity or were washed by streams. The decomposition of the limestone has formed manganese-bearing surface hollows and channels; elsewhere manganese-bearing caves and sinks have developed. Slumping and sinking of the soft, plastic clay (and of the overlying Cason shale) have greatly disturbed the ore bodies. These residual deposits consist of psilomelane, hausmannite, wad, and, subordinately, braunite. The hard oxides may occur as bowlders that weigh as much as 22 tons; generally the coarser the masses, the more free the ore from iron and the higher its grade.

Some small deposits of manganese oxides have been formed by the introduction of manganese into the clays through the action of ground waters; such manganese probably came from the Cason shale or Fernvale limestone. These ores are low grade and diluted though the presence of silica, iron, and alumina.

Finally some manganese is obtained from alluvial cones and gravel bars, the deposits being composed of compact masses of manganese oxides, and of small pebbles of oxide of iron. Many of the largest concentrations

lie in synclines, for reasons which the writer hopes to demonstrate in a later paper.

Most of the high-grade ores bear from 45 to 52 per cent of manganese, but many otherwise good deposits bear too much phosphorous to justify exploiting them. "Hand-picked" ore is the highest grade. The ore is not used for chemical purposes, but is employed in various high-manganese iron and steel products; it is also of importance in making brown, gray, and speckled bricks, when mixed with clay.

The manganese reserves probably amount to 25,000 tons of 40 per cent manganese. The deposits are covered to the south by younger formations, and could probably not be extensively worked in that direction anyway, since concentration and oxidation have not been extensive under the heavy capping.

C. H. B., Jr.

Magnesite Deposits of Grenville District, Argenteuil County, Quebec. By M. E. Wilson. Memoir 98, Canadian Geological Survey, Ottawa, 1917. Pp. 88, figs. 2, pls. 11, maps 3.

This district is bordered by the Ottawa River on the south and is about halfway between Ottawa and Montreal. The magnesite deposits are about ten miles north of the Ottawa River.

Chapter i gives information of general interest about magnesite, its uses, foreign source of supply, other Canadian magnesite deposits, and the history of magnesite mining in Grenville district.

Chapter ii is a brief statement of the geology of the district. The oldest rocks belong to the Grenville sedimentary series and are intruded by pyroxene-rich gabbro, diorite, and syenite belonging to the Buckingham series. These two series are intruded by batholithic masses of granite-syenite gneiss. All these rocks are intensely metamorphosed and are Early pre-Cambrian in age. These Early pre-Cambrian rocks are intruded by diabase dikes and a stocklike mass of granite-syenite probably of Late pre-Cambrian age. The Paleozoic is represented by the Potsdam, Beekmantoan and Chazy formations named in ascending order. Glacial bowlder clay and gravel and Champlain marine clay form an irregular mantle over the bed-rock surface.

Chapter iii gives a description of the magnesite deposits and their origin. The magnesite is associated with serpentine, dolomite and other minerals in the metamorphosed Grenville sediments and close to outcrops of the pyroxenic rocks of the Buckingham series. The deposits are lens-shaped and the material is banded, the banding being due to

differences in color of the magnesite or from variations of amounts of serpentine and other minerals present. The strike of the bands and lenses is parallel to that of the Grenville sediments. The deposits have been intensely faulted and crumpled and probably the lenticular structure is the result of deformation. The mode of occurrence of the following minerals associated with the deposits is described: magnesite, serpentine, dolomite, diopside, phlogopite, quartz, talc, pyrite, sphalerite, magnetite, and graphite.

The three methods of origin for magnesite deposits are: (1) deposits formed by the decomposition of serpentine, (2) sedimentary deposits, (3) deposits formed by the replacement of limestone. The Grenville deposits are thought to have been formed by the replacement of limestone. Silication of limestone to diopside and phlogopite is very common along the contacts of limestone and igneous rocks in this region and the igneous rocks are very close to these particular deposits. The writer summarizes the method of origin: "The probable order of events by which the magnesite deposits of the Grenville district were formed was as follows: (1) silication of the limestone to diopside and the formation of phlogopite in places, (2) formation of serpentine in places, (3) replacement of limestone by dolomite, (4) replacement of dolomite by magnesite, and (5) the alteration of diopside to serpentine."

Chapter iv is a detailed description of the properties and gives tabulated descriptions of many magnesite samples with the percentage of CaO. While dolomite and magnesite are very intimately intermingled, yet by 1916 development work had proved the presence of 686,900 tons of magnesite containing less than 12 per cent CaO and 483,700 tons containing over 12 per cent CaO.

Map 1680 issued in 1919 shows in detail the geology of a portion of the township surrounding the deposits.

J. F. W.

Pleistocene Marine Submergence of the Hudson, Champlain and St. Lawrence Valleys. By HERMAN L. FAIRCHILD. New York State Museum Bulletins, Nos. 209, 210, Albany, N.Y., 1919. Pp. 76, pls. 25.

This is the closing paper by Professor Fairchild on the glacial and post-glacial waters of New York State and in it he discusses the proof and extent of the marine submergence following the retreat of Wisconsin glacial ice from northern New York State. The stratified clay and

sand in these valleys, the cobble bars, the wave-cut terraces, the deltas, and many other evidences of high-level standing water, with no known barriers to hold this water in, is strong evidence that the land in this region once stood below sea-level. This marine shore line has been uplifted and tilted and is now less than 100 feet above sea-level a short distance north of New York City and 740 feet above sea-level at Covey Hill on the International boundary, a distance of about 350 miles. Diagrams are given to show the profile of this tilted marine shore line and also the shore line of Lake Iroquois, the last of the glacial lakes to occupy the Ontario basin. In the St. Lawrence-Ontario basin the Iroquois plane is 290 feet above the marine plane and thus when one is found in the field it is easy to locate the position of the other. Also knowing the present elevation of these two planes and the total amount of uplift of the region, the amount of either glacial or post-glacial uplift can easily be determined. From numerous measurements and calculations of this sort it appears that northern New York State was not raised as a rigid body but by a progressive wave movement, as the southern side of Iroquois basin received one-half its total uplift during Iroquois time while the northern end of the same basin received very little uplift until after Iroquois time. The uplift of the land seems to have been wavelike and to have followed the margin of the retreating ice front.

Detailed descriptions of shore features in the various sheets along the Hudson, Champlain, and St. Lawrence valleys and the Ontario basin are given. The shore features at Covey Hill, the point of junction of the Champlain and St. Lawrence valleys and of the Champlain marine waters and the Lake Iroquois waters, are described in detail. Some of these shore features are at present somewhat above what the level of the water should have been at these particular localities. Many complications probably enter the Pleistocene history as there may have been many up-and-down land movements and the present height of the summit plane above the sea must represent only the excess of land uplift over the rise of the ocean surface and the arithmetical sum of all the up-and-down movements.

A large number of photographs are inserted to show summit shore features and at the end of the report a classified bibliography is given. This report summarizes in a very thorough and clear manner Professor Fairchild's interpretation of the various glacial and post-glacial deposits and physiographic features of this region.

J. F. W.

Iron Depositing Bacteria and Their Geological Relations. By EDMUND CECIL HARDER. United States Geological Survey, Professional Paper 113, 1919, Government Printing Office, Washington. Pp. 85, pls. 12, figs. 13.

Geology, probably more than any other science, occupies an apical position in the pyramid of the natural sciences; its function is not so much to enunciate the more fundamental theories *not* based on the concepts of other branches of knowledge, as to weld together the contributions of its sister-sciences and apply them to its own purposes. From this point of view a work such as that under review is especially illuminating; it demonstrates conclusively the hitherto only partially appreciated breadth of scope of the "science of rocks and minerals."

The paper begins with a careful description of the living iron-depositing bacteria, both those of the higher and those of the lower type. Not only the more common forms, such as Leptothrix, Galionella, and Spirophyllum are mentioned, but a brief review of the classification, morphology, and physiology of essentially all relevant forms known to date is given. The iron-bearing algae also are named. From the early work of Cohn and Zopf, who thought iron accumulation in bacterial sheaths essentially a mechanical process, through that of James Campbell Brown, who considered the deposition of ferric hydroxide to be merely incidental to the extraction of the organic constituents in the water affected, to the studies of Lieske, which demonstrated conclusively that the carbonate radicle of ferrous carbonate is extracted by the bacteria, leaving the insoluble hydroxide, the increasing importance of bacterial metabolism has come to be recognized. It is probable, in fact, that some bacteria require ferrous bicarbonate; that others can use it interchangeably with other soluble iron compounds; while still others, notably the lower groups, can use only the organic salts of iron.

Mr. Harder himself prepared and studied cultures of various forms. Crenothrix was obtained from city water of Madison, Wisconsin, which contained large amounts of magnesium and calcium carbonates. Cultures of Leptothrix ochracea were grown from the water of a chalybeate spring near Madison, the water bearing much ferrous iron in solution, probably as the bicarbonate; this form was also brought up from a low level of a Cuyuna District mine, where ferric hydroxide is being precipitated in large amounts. Cultures of Galionella ferruginea from the Federal Mine of Wisconsin and from the Kennedy Mine of central Minnesota are also reported; in both of these localities a brown, gelatinous scum occurs on the walls of the tunnels and in little pools in the drift-floors. Spirophyllum ferrugineum appears in the waters of the

Wisconsin zinc mines; it was also found in other mine-waters, probably being carried downward by surface waters that descended through the soil and rock for many hundreds of feet. The form is especially abundant in the water of Vermilion Lake, Soudan, Minnesota. All these bacteria precipitated ferric hydroxide.

Besides these there are other iron bacteria which precipitate ferric hydroxide or ferrous sulphide. The former group is especially widespread, and though its members do not require iron in solution for their development, still it is thrown down quite rapidly as a waste product. The precipitating action of such forms was studied by means of weak solutions of the slightly acid ferrous ammonium sulphate.

Whereas some of the sulphide-precipitating bacteria owe this ability to the action of the hydrogen sulphide liberated by them on the ferric salt in solution, others precipitate the sulphide because of their reducing action on the sulphate. When water bearing ferric ammonium citrate was inoculated with hay and soil infusions, there resulted a precipitation of ferric hydroxide not observed in the sterile solution. This ensues even under anerobic conditions. The organisms that induced it were grown on plates of Heyden Naehrstoff agar with ferric ammonium citrate as indicator and various types of bacteria were recognized. Slopes of Heyden agar to which no citrate was added showed practically no growth. Other organic salts of iron were also used more or less successfully, and similar experiments showed that no precipitations resulted from the solutions bearing salts of manganese in place of iron.

On the other hand, no precipitation that could be definitely assigned to organic processes could be obtained from inorganic iron salts such as the bivalent carbonate or sulphate or ferric chloride, the precipitation that *did* result in these cases being better attributed to the purely inorganic oxidation and (or) hydrolysis. These results do not agree with those of Mumford (*Chem. Soc. Jour.*, Vol. 103, 1913).

A review of the earlier work of Beijerinck, Van Delden, and Fred on the formation of hydrogen sulphide by bacteria may be summarized as follows: sulphates are formed abundantly by sulphur bacteria from hydrogen sulphide; these sulphates are then reduced by other bacteria to yield sulphides and hydrogen sulphide; if ferrous or manganese sulphides are formed they are precipitated. These observations have been ably and fully discussed in other papers, notably in their bearing on the origin of the Sicilian sulphur deposits.

The relations of these facts to geologic processes are amplified by the writer. He points out the solubility of iron carbonate; soluble organic compounds, chiefly humides, of iron may also be formed; it is

these that lend the dark color to streams flowing through regions of abundant vegetation. Finally, a smaller amount of iron may be carried as sulphate.

Iron deposits occur in the form of hydroxides and oxides, carbonates, and silicates. Iron is readily precipitated as the hydroxide, when a solution containing an excess of carbon dioxide is induced, through changes in pressure or temperature, to give up its gas with a concomitant saturation with oxygen; if the solution merely loses its carbon dioxide without undue oxidation, ferrous carbonate tends to be precipitated. These several iron precipitates generally accumulate in bogs, lakes, or lagoons. Elsewhere rapidly flowing waters may (rarely) form iron deposits.

Most deposits of bedded hematite, bog ore, and brown iron ore were laid down originally as hydroxides, chiefly through biologic, but also in part through chemical, agencies. Iron sulphide, too, may be formed in either way, but ferrous carbonates and silicates are not definitely traceable to bacterial action. Iron phosphates and basic ferric sulphates are chemical precipitates. Ferrous silicates tend to be deposited where alkaline silicates are abundant in regions of precipitation of ferrous carbonates—formed as indicated above. Probably 90 per cent of all the iron ores being worked today are of the sedimentary type. A list and description of those thought to be originally laid down as ferric hydroxide includes the Clinton ores, the Wabana ores, the Lake Superior hematite-chamosites, the itabirites of Minas Garaes, (Brazil) the hematite-magnetites of the Dharwar terrain of India, and the ores of the Norwegian Lias. Bog iron ores, too, were probably deposited in the same form and are now widely distributed, being especially abundant in the eastern part of Canada and the United States, in Sweden, and in the glaciated sections of Europe and Asia; ferric hydroxide is also present in large amounts in the red mud off the coast of Brazil.

Another type of sedimentary iron ore is that originally deposited as the carbonate; this is represented by the "black band" ores in Ohio, Pennsylvania, and West Virginia, the oölitic siderites of eastern England, and the siderites of the Lake Superior region.

The silicates present a third type of sedimentary iron ore. The forms in which the iron occurs include glauconite, bavalite, thueringite, bertherine, and chamosite; of these glauconite is the most widespread. Greenalite was probably the original constituent of the Mesabi ores, while the chamosite ores are predominant in the Bohemian Brdagebirge.

Ferric and ferrous sulphides represent the fourth type of iron deposits. Pyrite is important in the Huelva region of southern Spain, in the

Carpathian and Harz Mountains, and in Westphalia; the sedimentary origin of some of these beds, however, is still in doubt; more typically sedimentary are some of the oölitic pyrite beds of Wabana. Ferrous sulphide is common in the limans of the Black Sea. The general explanation offered for these deposits is that of Doss, who believed that the iron is carried as a carbonate, upon which bacteria may act directly or indirectly to yield colloidal ferrous sulphide or ferric hydroxide, which in turn is converted into ferrous sulphide.

Various facts of importance to students of sedimentation are brought out in a discussion of the origin of the separate iron deposits; for instance, the experiments by Spring and Ruff on the conditions favoring and opposing the derivation of limonite from ferric hydroxide. It is shown, also, that primary deposits of ferric hydroxide may be readily altered to the carbonate, especially in the presence of large amounts of organic matter.

From a discussion of the inorganic causes for the precipitation of iron compounds as sediments, the writer returns to a consideration of organic causes. Here, especially in connection with the precipitation of ferric hydroxides, the line is not readily drawn between oxidation, taken as the purely inorganic process, and bacterial action; the latter, however, is surely of much importance, whether actually preponderant or not. The conditions under which iron-bearing bacteria are active vary between wide limits. Temperature, if too high or too low, may be inhibitory, as may also be a reduction in the amount of organic matter present.

To present in detail all the significant facts of this interesting paper, would necessitate a review as long as the original publication; it must be read to be fully appreciated. It displays both the clear thought and the technical skill of Mr. Harder in original work and his ability to join his observations to those of other investigators of the subject. All in all, it is a most admirable contribution to experimental geology.

C. H. B., Jr.

Helium-Bearing Natural Gas. By G. Sherburne Rogers. United States Geological Survey, Professional Paper 121. Washington, 1921.

This report comes from the press many months after the accidental death of its author in South America. It reflects so zealous a spirit of scientific research in the public service that it stirs anew the sorrow of

his former associates at the passing of a geologist of such brilliancy and promise. The report perpetuates one of Mr. Rogers' contributions to the war needs of his country, namely the investigation of the occurrences of helium-bearing natural gas in the United States with a view to its utilization in dirigibles and military balloons.

Helium differs from hydrogen, the gas commonly used in balloons, in being non-inflammable; on the other hand it is about twice as heavy as hydrogen though still so much lighter than air that its lifting-power in air is 93 per cent that of hydrogen. Its advantages are so great that its use, both commercial and military, in airships is likely to be limited solely by the supply of helium available and the expense at which it can be produced.

The main body of this report is devoted to a description of the field occurrence of natural gases containing helium within the limits of the United States, but a brief discussion of possible sources of helium in other countries is included, and the report summarizes also, in very concrete and admirable fashion, the history of helium, its properties, and its relations to the radioactive elements, as well as the methods which have been applied for separating it from the commoner constituents of natural gases. The field work upon which the investigation rests consisted chiefly in collecting samples of gas for analysis and in gathering data regarding depth, geologic position, rock pressure, and volume of the gas sampled. This work involved careful examination of the geological structure in one or two areas, though a number of helium-rich districts had been previously studied by Survey geologists, and data on others were furnished by oil companies.

As a result of the investigations it is shown that although most of the natural gas produced in the eastern and central parts of the United States contains at least a trace of helium, gas containing more than $\frac{1}{2}$ per cent is known to occur only in two areas, one in northern Texas and the other in southern Kansas and northern Oklahoma. The helium-rich gas of the Kansas-Oklahoma area is confined to strata of Middle and Upper Pennsylvanian age, though gas carrying almost $\frac{1}{2}$ per cent of helium occurs in the Lower Pennsylvanian. The Mississippian and Permian gases in that locality are poor in helium. Conditions in the Texas area are almost identical. In Ohio gas carrying $\frac{1}{3}$ per cent of helium occurs in the Lower Mississippian and in the Clinton of the Silurian. Nearly all samples of Cretaceous gas from various parts of the United States show only traces of helium and most samples of Tertiary gas contain none.

Although traces of helium occur in most natural gas, noteworthy proportions have been found only in gas rich in nitrogen. The percentage in helium, moreover, seems to depend, in a measure, on the percentage of nitrogen, though there is not direct proportionality between the two. Some of the Kansas gases contain about 85 per cent of nitrogen and 2 per cent of helium.

After a discussion of the occurrence of helium in minerals and rocks, in mine gases and in the gases of mineral springs, volcanoes and fumeroles, the theories that have been advanced in explanation of the origin of the helium in natural gases are discussed. While recognizing that the origin of the helium is still a matter of great uncertainty, the writer is inclined to favor the view that the helium is derived from deposits of uranium and thorium, probably disseminated through the strata not far beneath the horizons at which the helium gas occurs.

E. S. BASTIN

The Economic Aspects of Geology. By C. K. LEITH. New York: Henry Holt and Company, 1921.

Because each year modern industry is becoming more technical, industrial progress has come to stride pace after pace with the development of science. Geology has shared with other sciences in the tightening of the bonds between science and industry. It is no longer necessary, as it was a generation ago, for the geologist to be continually bringing before the public the practical potentialities of his science; certain industries are now even snatching the half-fledged geologists from their academic nests. The increasing industrial importance of geology lays a new responsibility upon those engaged in the training of economic geologists, and Professor Leith's book, an embodiment of lectures given at the University of Wisconsin, drives home to the geology student in vigorous fashion not only the fundamental facts of useful mineral occurrence but also the rôle which each of these minerals plays in the economic life of the nation and of the world. The book is, in fact, an outgrowth of its author's war-time experiences during which he distinguished himself as a leader in the first real inventory of her mineral resources that the United States had ever taken.

The work is adapted to the use of students having an elementary knowledge of geology, such, for example, as is commonly acquired in the first year's work in college geology. While adapted for the use of

students, most mining engineers and teachers of geology will find that it gives them not only a new array of facts, but a broadened viewpoint.

After introductory material, a chapter is devoted to the common elements, minerals and rocks of the earth and their origin, and another chapter to a simple exposition of the processes by which mineral deposits are formed.

In the consideration of individual mineral resources, the conventional classification as metallic and non-metallic is abandoned in favor of one that is more expressive of their rôle in industrial life. Early in the scheme come the fertilizer group of minerals, nitrates, potash, phosphates, pyrite, and sulphur. Then come the fundamental fuels, coal, oil, and gas. In the same chapter with iron and steel are treated the ferro-alloying minerals and the minerals fluorite, magnesite, and silica, that find their main use as fluxes or refractories in the iron and steel industry. Other major base metals are followed by the precious metals, and then by minor metals. The commodity chapters are concluded with one devoted to miscellaneous non-metallic minerals.

A feature of the treatment of individual commodities that makes for clarity is the treatment of "Economic Features" and "Geologic Features" under separate heads.

Conservation of mineral resources, particularly coal, comes in for separate treatment in a chapter near the end of the volume. Especially noteworthy are several topics that have received scant treatment, if any, in previous books on economic geology; namely, exploration and development of mineral deposits, the rôle of the geologist in their valuation and taxation, and a brief discussion of the legal aspects of geology.

The book concludes with chapters summarizing the international aspects of mineral resources, on "Geology at the Front" and "Geology Behind the Front."

The field occupied by this book is covered by no other, and few books are likely to fill as useful a place in geologic education.

EDSON S. BASTIN